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Translation

AEROSPACE METHODS FOR THE STUDY OF SOILS

By

Valeriy L'vovich Andronikov

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AEROSPACE METHODS FOR THE STUDY OF SOILS

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CONTENTS

ANNOTATION

[Text] The book describes the theoretical principles of methods for interpretation of the soil cover from its image on photographs from aerial and space surveys of the earth's surface. The use of materials from multizonal and multispectral surveys for the study of soils is discussed for the first time.

Preface

This book presents the first experience in a monographic generalization of materials from aerospace surveys for the study of soils. As a result of the vigorous development of space research methods in the USSR, United States and other countries a number of new directions have appeared in this field: space meteorology, aerospace geology, space cartography, space geography and others having as their objective the further investigation of the natural resources of our planet.

In an investigation of the earth's resources an important role is played by materials supplied by automated artificial satellites, manned spaceships and orbital stations. A full range of photographic and television systems and methodological procedures has now been developed for surveying the earth's surface using aerial and space vehicles with subsequent visual-instrumental and optical-electronic processing of the collected materials.

In the near future the use of aerospace remote methods will make it possible to solve many problems in the quantitative and qualitative inventory and study of the soil resources of the USSR. This monograph will be of assistance in solving these problems. It gives an analysis of methodological procedures for the study of the soil cover from the "Meteor" experimental satellites, "Soyuz" spaceships and "Salyut" orbital stations. The possibilities of the MKF-6 camera ("Raduga" experiment) for an aerospace multizonal survey are demonstrated.

The author presents the results of many years of investigations of the use of black-and-white, spectrozonal, multizonal and multispectral aerial and space photographs for study of the soil cover and also data from infrared, radiothermal and radar surveys for soil-agricultural purposes.

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INTRODUCTION

At the present time the attention of Soviet and foreign researchers is being given to the use of aerospace materials for study of the soil cover.

In the "Principal Directions for Development of the USSR National Economy in 1976-1980" the need was pointed out for the expansion of research with the use of space vehicles in studying the earth's natural resources. Remote aerospace methods are objective high-speed automated systems for the collection and processing of information on the state of soils, agricultural fields and sown areas. The control of agricultural production can be organized more effectively on this basis.

One of the new directions in the field of use of aerospace methods for the study of soils and sown areas of agricultural crops is the development of multizonal and multispectral aerial and space surveys. In this method one and the same sector of the earth's surface is photographed simultaneously in several narrow spectral ranges. As a result photographs are obtained which carry the maximum information concerning the soil cover and agricultural crops.

The use of infrared photographic, photoelectronic and radar surveys is highly promising in agriculture (for studying the soil cover and sown areas). A radar survey can be used in the absence of visibility (through clouds and even at nighttime). Using radar photographs it is possible to interpret moisture content, some structural elements and the diversity of the soil cover, the makeup of the upper horizons and the types of agricultural crops.

A space survey of the soil cover and sown areas of agricultural crops, in comparison with an aerial survey, for the first time is making it possible to see soils and agricultural crops objectively simultaneously over extensive areas, individual mountain systems and the vertical zonality of the soil-vegetation cover and the nature of irrigation and drainage systems as a whole. Another important characteristic of a space survey is that on space photographs there is an objective generalization of the soil cover; in addition, these photographs make it possible to interpret the soil cover in individual, frequently inaccessible regions. The use of space materials will assist in a more thorough study of soils.

One of the principal and fundamental characteristics of a survey from space is the routineness in the collection of information on the state of the soil cover, the nature of snow melting, the development of erosional processes and the state of agricultural crops at a national scale. Still another characteristic of a space survey is the possibility for a rapid repetition of the survey. This is especially important for judging rapidly developing dynamic soil-agricultural processes transpiring at the earth's surface.

Aerospace (remote) methods, with the use of corresponding detectors carried on flight (air and space) vehicles, on the one hand register the reflection of sunlight from soils and vegetation, and on the other hand, detect the characteristic radiation of the soil-vegetation cover of the earth's surface.

The use of aerospace methods is based on the fact that the absorption, emission, scattering and reflection of electromagnetic energy by different soils and sown areas is selective and specific for each soil and agricultural crop.

The interpretation of the soil cover is carried out on the basis of its image on aerial and space photographs, including multizonal photographs. Studies are made of the interpretability and possibility of using aerospace photographs taken in different zones of the electromagnetic spectrum for investigating the soil cover and keys are being developed for soil interpretation.

Investigations of soil interpretation in the field were carried out in the territory of the steppe, dry steppe and desert zones of our country.

Investigations in the field of interpretation of the soil cover, agricultural crops and virgin land vegetation have been made using black-and-white, color and spectrozonal aerial photographs, multizonal aerial photographs (green, red, IR zones), obtained using an AFA-39M outfit during the survey of 1973-1975, multispectral aerial photographs obtained using a scanner, black-and-white space photographs from the "Soyuz-9," "Salyut-1" and "Salyut-4," multizonal space photographs from the "Soyuz-12," "Salyut-4" and "Soyuz-22" and from the "Meteor" experimental satellites.

In this monograph we also give an analysis of foreign black-and-white and color space photographs from the "Gemini" and "Apollo" vehicles and multispectral space photographs in four zones of the spectrum from the ERTS satellite "Landsat," obtained for the territory of the USSR and foreign countries.

The joint use of aerial and space photographs is the optimum variant for interpreting images of the soil cover and vegetation. The interpretation of aerial photographs is used most successfully in key sectors for studying structural elements of the soil cover. However, in the interpretation of space photographs soil scientists meet with a generalized image of the soil surface. The investigation and interpretation of aerial and space photographs begin with a preliminary office work period, the importance of which increases with the use of multizonal photographs and stereoscopic, optical-electronic and photometric apparatus for the processing of photographs and films.

The interpretation of aerospace photographs included field surface work for investigating the soil cover and sown areas of agricultural crops and checking the results of office interpretation. In the work use was made of materials from the book of the history of fields, taking into account data on crop yields. In office and field interpretation, in addition to data from field investigations, use was made of existing soil and topographic maps of different scales, plans for the distribution of agricultural crops and materials in the literature.

In the analysis of aerospace materials use was made of the stereoscopic research method, employing a stereoscope and an interpretoscope. The spectral reflectivity of the soils was measured using air-dried samples, employing an SF-10 spectrophotometer. In the investigation of aerospace photographs use was made of an MF-4 microphotometer and the quantitative visual-instrumental interpretation method, employing the modern "Kvantimet-720" electronic-optical image analyzer. Chemical analyses of soils were made in the Mass Analyses Laboratory of the Soils Institute. In addition to experimental surveys made by the Soils Institute, extensive use was made of materials from multizonal experimental flights of the Space Research Institute USSR Academy of Sciences. A considerable part of the space photographs was furnished by the State Center "Priroda" of the Main Administration of Geodesy and Cartography of the USSR Council of Ministers and the State Scientific Research Center for the Study of Natural Resources of the USSR State Committee on Hydrometeorology and Environmental Monitoring.

Chapter 1

HISTORY OF AEROSPACE METHODS FOR STUDYING SOILS

The initial stage in the development of remote methods for investigating soils is related to the use of aerial surveys. Aerial photographic surveys in soil science, introduced in the 1920's, in a relatively short historical period made an enormous stride forward.

Development and Introduction of Aerial Methods for Study of the Soil Cover (1927-1950)

The first experimental studies in the Soviet Union on the use of an aerial survey for soils and agricultural purposes were carried out in the Fergana valley in 1927.

The importance of an aerial photographic survey as a new method for studying natural resources was outlined by Academician A. Ye. Fersman (1928). He wrote that an aerial survey gives a precise and objective photographic image of a territory. It makes it possible to repeat surveys during different periods and ascertain the changes which are introduced by nature and man's economic activity in the course of a definite time period. In 1927 in the United States (Bushnell, 1927, 1929) aerial photographs were used in soil mapping for the state of Indiana. It was established on the basis of the first investigations that areas of uniform soils could be discriminated reliably on aerial photographs and then, employing a pantograph, could be plotted on a map base.

At approximately the same time attention was given to the use of aerial methods in Australia (Prescott, Taylor, 1930).

Large-scale soils investigations assumed a broad scale in the USSR during these years. During the years 1929-1931 alone soil maps at a scale 1:10,000, 1:25,000, 1:50,000 were compiled for a territory with a total area of about 50,000,000 hectares. Materials from aerial photographic surveys began to be used with increasing frequency in a study of soils. In investigating the territory of Don River plavni (low areas covered with reeds and trees) (Levengaupt, 1932) it was found that aerial photographs have a considerable advantage over plane-table surveys with plotting of contours. The aerial photographs clearly depicted all the details of the vegetation cover, this being related to the character of the soils to be mapped. As a result, the boundaries between the soil varieties were drawn with a high degree of accuracy.

Among the earliest soil mapping studies with the use of materials from aerial surveys we must also include the soil surveys of Giprovod (State Institute for the Planning of Water Resources) in 1930-1931. Aerial photographic materials were used both as a base and for the interpretation of the soil cover. During 1931-1932 aerial photographs were successfully used in a soil melioration survey of the Volga-Akhtubinsk floodplain and the Volga delta.

In 1931 Academician L. I. Prasolov wrote that the best prospects for the use of aerial methods in soil science were opening up in the field of investigation of inaccessible swampy regions and in compiling detailed soil maps of cultivated regions. In 1933 he indicated that an aerial photographic survey is a new method for carrying out soil investigations.

During 1932-1940 aerial photographs were used in work on the mapping of soils carried out in the Ukraine and the Urals, in Kazakhstan, Siberia, Central Asia and in other regions of our country. It was established on the basis of these studies that in comparison with surface survey maps the principal advantage of materials from an aerial photographic survey is assurance of orientation in the terrain, accuracy and detail in plotting the boundaries of areas of uniform soil. Work productivity in soil mapping of a territory with the use of aerial methods doubles or triples.

Abroad, in studies involving the use of materials from an aerial photographic survey for investigating the soil cover (Belcher, 1948; Frost, Woods, 1948; Troll, 1939), mention is made of the need for using the interrelationships existing between soils and landscape elements in interpretation work. For example, using the relationship between the soil and vegetation cover, by means of interpretation of vegetation it is possible to determine the soil cover of the investigated territory. In soil investigations the materials from an aerial photographic survey serve for supporting, assisting and deepening work on the mapping of a territory. During the period of development and introduction of aerial methods for study of the soil cover it was established by a number of Soviet and foreign researchers that when using aerial photographs there is an increase in the accuracy of the results and a decrease in the cost of the work.

Aerial Methods in Soil Mapping Work in Different Natural Zones of the Country (1950-1970)

During the post-war period, both in the Soviet Union and abroad, aerial methods came into extensive use for the purpose of study of the soil cover. This stage is characterized by the use of already available aerial photographic materials in the mapping of soils, as well as the formulation of special investigations.

In 1950, in a specially organized laboratory for the large-scale mapping of soils at the Soils Institute imeni V. V. Dokuchayev, under the direction of Yu. A. Liverovskiy, work was initiated on a method for compiling large-scale soils maps on the basis of aerial methods in different soil-geographic zones of our country. The aerial survey was regarded as a new method making it possible to compile soil maps of a fundamentally new content. Similar work in the field of soil aerial methods was initiated during this period in the Aerial Methods Laboratory USSR Academy of Sciences and at Moscow State University. The tasks and possibilities of such work were dealt with in an article by A. V. Gaveman and Yu. A. Liverovskiy (1953). In this study the authors pointed out the need for developing a method for the interpretation of aerial photographs for study of the soil cover, the use of a special aerial survey -- color and spectrozonal, study of the spectral reflectivity of soils.

During the post-war period in all the principal soil-geographic zones of our country investigations were made for studying the distinguishing characteristics of the interpretation of soils and their mapping on the basis of aerial materials. In the studies of Soviet specialists published during this period there were investigations of the possibility of interpretation and use of materials from an aerial survey for the study and mapping of the soil cover in the forest, wooded steppe, steppe, dry steppe and desert zones of our country.

The dependence between spectral brightness and humus content, mechanical composition, moisture content, nature of the surface and other soil factors and properties was established. The landscape principle for interpretation of the soil cover was proposed. The problems involved in large-scale and medium-scale soils and soils-meliorative surveying were considered. The influence of natural and technical conditions for carrying out this work was established. Color spectrozonal aerial surveying of the soil cover was beginning to acquire great importance; with respect to the degree of interpretability of soils this had considerable advantages over a panchromatic survey.

The considered period (1950-1970) saw the beginning of the use of aerial methods in special soil investigations: erodability of the soil cover, soil melioration work and soils regionalization. A number of generalizing manuals were devoted to the methods employed in the mapping of soils on the basis of aerial methods. It was exceptionally important to introduce a course on the interpretation of soils into the curricula of universities and other higher educational institutions.

Color spectrozonal aerial surveying began to come into increasing use in studies for the mapping of soils. Among the color films Soviet spectrozonal and American (Kodak Company) films have good properties for making surveys in natural and "fictitious" colors; Czechoslovakian, Belgian and Swiss films have good natural reproduction of colors.

Work done in this stage dealt with the possibilities of using color spectrozonal photographs for the interpretation of soil cover in soddy-podzolic, gray forest, chernozem and chestnut zones. The advantages of their use in comparison with panchromatic photographs were clarified. In the socialist countries, especially in East Germany, Soviet spectrozonal film has been used successfully in the interpretation of meadow soils (Asmus, Reinhold, 1966).

In 1952 the Scientific Research Institute of Soils and Fertilizers (United States) generalized and systematized the requirements imposed on an aerial survey used in study of the soil cover (Swanson, 1954). It was established that a scale of 1:20,000 was in the widest use for the mapping of soils. The time for the survey is selected in dependence on the region, but in most cases an aerial survey is made in spring when the soil is freed of snow and has a minimum vegetation cover.

In addition to individual studies of the use of aerial methods in a soil survey and on the interpretation of soils, during this period special manuals on the engineering interpretation of soils (MANUAL OF AIRPHOTO INTER-INTERPRETATION..., 1953) and on general interpretation problems (MANUAL OF PHOTOGRAPHIC INTERPRETATION, 1960, AERIAL PHOTOINTERPRETATION..., 1966) were published.

The American Photogrammetric Society prepared and published a special manual on color aerial photographic surveying (MANUAL OF COLOR AERIAL PHOTOGRAPHY, 1968) containing data on the use of color photographs in different branches of the natural sciences.

In the United States, Sweden, West Germany and other foreign countries extensive use is made of a color aerial photographic survey on reversible color film and printing on color reversible paper, which make it possible to obtain a better image of color transmission than negative color film (Gerberman, et al., 1971, Kuhl, 1970).

In the USSR, United States, France and other well-developed countries work is being done on the compilation of aerial photograph keys, playing an important role in the office interpretation of soils.

Abroad the post-war period is characterized by the extensive use of aerial methods in soil science. In a review report prepared for UNESCO (Vink, 1968) it was indicated that only during recent years has there been a more systematic and fundamental approach to the problem of use of aerial survey materials for study of the soil cover. In the United States during these years a considerable part of the agricultural areas was covered by an aerial survey at a scale of 1:20,000; in addition to panchromatic films, infrachromatic films are used extensively in soil surveys. Soils are interpreted both in the office and in the field. Interpretation criteria have now been developed for all soil varieties in the United States and the key criterion for interpretation of the soil cover is the interrelationship between soils and vegetation. Special investigations for the interpretation of soils are made at a number of universities in the United States (Clark, 1957; Muir, 1955).

In Holland much academic and scientific research work on the interpretation of soils was carried out by the International Institute of Aerial Surveying and the Earth Sciences (Veenenbos, 1956).

Much work on the study and mapping of natural resources and soils was done in France and other countries. Serious work on the study of the natural resources of the developing countries with the use of aerial methods was carried out during this period by the Sciences Department of UNESCO, whose general director over a period of years was V. A. Kovda, Corresponding Member USSR Academy of Sciences.

In many foreign countries -- Great Britain, Australia, Belgium, Holland, India, Italy, Canada, Mexico, United States, West Germany, France, Sweden, Japan -- aerospace (remote) methods were then used successfully in the study of natural resources, including the soil cover, when making a soil survey. Firms in a number of countries (United States, Great Britain, Holland, Italy, Canada, France) carried out similar survey work in developing countries of Asia, Africa, Latin America. The studies made by foreign specialists during this period outlined the characteristic peculiarities of interpretation of soils from aerial photographs, the good prospects for the use of aerial methods in study of the soil cover and the effectiveness of use of color spectrozonal photographs.

During the considered period (1950-1970) of development of aerial methods in the USSR and foreign countries an ever-increasing role was played by soil aerial methods in the mapping of soils carried out in different natural zones over the earth. Color and especially spectrozonal aerial photographic surveying of soils was beginning to acquire ever-greater importance.

Modern Stage in Aerospace (Remote) Methods in Soil Science and Agriculture (1970-1979)

This period is characterized by improvement in the earlier developed interpretation methods and a changeover from description of the characteristics of the investigated object to quantitative indices.

In the USSR a number of systematic manuals have been published on the mapping of the soil cover with the use of materials from aerial surveys (KRUPNOMASSHTABNAYA KAROGRAFIYA POCHV, 1971; Afanas'yeva, et al., 1977).

Special fundamental investigations have been carried out for studying the optical properties of the landscape applicable to an aerial survey (Tolchel'nikov, 1974), and also an analysis of spectral reflectivity and soil color as indices of their properties (Karmanov, 1974).

In carrying out an experimental soil aerial survey in our country and abroad great attention during these years was being devoted to the choice of technical and natural conditions for carrying it out, standardization problems, preliminary and office interpretation, development of interpretation keys for soils in different geographical zones and the landscape interpretation method. Aerial methods are being used on an ever-broader scale in soil melioration investigations.

This period has been characterized by the successful use of aerial methods in soil investigations in Belorussia, Moldavia, Kazakhstan, the Baltic and Transcaucasian republics, in the Ukraine, Central Asia and Siberia.

A new direction is the development and use of data from a remote aerospace survey in study of the soil cover and agricultural resources.

The studies of Soviet scientists have demonstrated the broad possibilities which are opening up in study of the earth's natural resources using space vehicles. A new branch of science is being created -- space geography, as pointed out in 1971 by B. V. Vinogradov and K. Ya. Kondrat'yev.

We can note the advantages of space methods for study of the environment -- the globality, regularity, periodicity and multisided nature of the observations, clarification of the relationships existing between natural features, the possibility of routine study of the dynamics of natural processes and phenomena and investigations of inaccessible natural regions. The introduction of space methods into geology, soil science, agriculture and other fields of science is creating new possibilities for study of natural resources, their space mapping, monitoring the state and preservation of the environment.

Special investigations are being made for studying the possibilities of using materials from a space survey in the field of soil science and agriculture. Using space methods it is possible to determine the types of soils, evaluate moistening conditions, ascertain the areas of agricultural fields and determine agricultural crops.

R. Chevallier (1973), in generalizing the materials of work in Commission VII (Interpretation) at the 12th Congress of the International Photogrammetric Society in Canada, noted that when using surveys from satellites the main problem is a study of the earth's natural resources, the development of optimum scales and conditions for the survey, the carrying out of multisided surveys from satellites and aircraft, as well as the interpretation of space images.

In the United States investigations in the use of space materials in the field of soil science and agriculture are being carried out by the Department of Agriculture in collaboration with NASA (National Aeronautics and Space Administration). During recent years one of the leading research studies was the compilation of the first photomap (by the Division of Soil Mapping and Protection of the US Department of Agriculture) of the entire country on the basis of photographs from the ERTS satellite at a scale of 1:1,000,000. A total of 595 photographs in the red zone (0.6-0.7μm) were used for this purpose.

At Purdue University (Indiana) M. J. Baumgardner, S. J. Kristof, C. J. Gahansen, A. L. Zachary and other researchers are carrying out work with the use of remote investigations for studying soils. Problems in the use of remote investigations in agriculture are also being made by the Experimental Agricultural Station in Weslaco (Texas), a number of universities and departments in the United States (Tyers, et al., 1966, 1969; Westin, 1974; Park, 1968).

In 1975 the American Society of Photogrammetrists published a fundamental work for the first time -- the MANUAL OF REMOTE SENSING. The first volume examines the theoretical principles and techniques used in remote surveys. The second volume is devoted to a photographic interpretation and use of remote methods, including study of agricultural crops and soils.

In Holland, at the International Institute of Aerial Surveying and the Earth Sciences the systematic training of specialists for study of soils with the use of remote methods is being conducted by D. Goosen and others. At the National Agronomic Institute in France investigations for the development of aerospace methods in the field of soil science and agriculture are being developed by M. C. Girard.

In the USSR two centers have been established for studying the earth's natural resources using space vehicles: the State Center "Priroda" of the Main Administration of Geodesy and Cartography of the USSR Council of Ministers and the State Scientific Research Institute for the Study of Natural Resources of the USSR State Committee on Hydrometeorology and Environmental Monitoring.

The great possibilities and prospects for the study of natural resources over the earth which are opening up with the use of space photographs constituted the subject of discussion at international and national conferences in different countries. In the USSR one of the first major scientific conferences for problems relating to study of the earth's natural resources from space was the All-Union Scientific School held at the Space Research Institute USSR Academy of Sciences in 1975 (AEROKOSMICHESKIYE ISSLEDOVANIYA ZEMLI, 1979).

The problems involved in the use of remote methods in the field of soil science and agriculture have been discussed in many countries and institutions, specifically: at Houston (United States) at conferences on the use of artificial earth satellites for geographic investigations in 1965 and 1975 using the results obtained with the "Skylab" orbital station; at 11 international symposia on remote sensing of the environment at the University of Michigan; at international congresses of soil scientists in Australia in 1968 and in Moscow in 1974; at the 12th International Congress of Photogrammetrists in Canada in 1972; at the 13th Session of COSPAR in Leningrad; at the 5th and 6th Congresses of the USSR Geopgraphical Society; at the 23d International Geographical Congress in 1976; at the 13th International Congress of Photogrammetrists in 1976 at Helsinki; at the International School in Rome and at other conferences.

Cooperation is developing between the USSR Academy of Sciences and NASA in the United States in the field of study of the earth's natural resources using space vehicles. One of the directions is the use of these methods for investigation of vegetation, soils and land use. The exchange of systematic attainments in this field between the USSR and the United States is of great theoretical and practical importance.

In the People's Republic of Bulgaria, Hungarian People's Republic, German Democratic Republic, Mongolian People's Republic, Polish People's Republic, Socialist Republic of Rumania and other socialist countries work is developing on the use of remote methods for study of soils and agricultural crops.

A session of the presidia of the All-Union Order of Lenin Academy of Agricultural Sciences imeni V. I. Lenin and the Academy of Agricultural Sciences of the German Democratic Republic was held in Moscow in 1977. There was discussion of problems relating to joint investigations of the use of multizonal space photographs taken with the MKF-6 camera for studying soils and agricultural crops.

The modern research period is characterized by the use of different remote aerospace, including multizonal and multispectral methods for study of the soil cover and areas of agricultural crops in the USSR and in foreign countries.

Chapter 2

AEROSPACE SURVEY OF SOIL-AGRICULTURAL RESOURCES AND EQUIPMENT FOR SUCH A SURVEY

A new method for the collection of information on natural resources has been developing during recent years in our country and abroad, especially in the United States. It has been given the name remote sensing. This term was introduced in 1960 by the geographer Evelyn Pruitt (United States) and is now being used throughout the world. In this method, without direct contact with the studied object, by the use of instruments it is possible to register electromagnetic waves reflected and radiated by the earth's surface from the flight altitude of an aircraft or artificial earth satellite (AES).

The totality of methods used in investigations and in mapping from an aircraft, artificial satellite, helicopter and other flight vehicles is known as aerospace methods for studying the earth's natural resources.

The physical properties and characteristics of soils and agricultural plantings can be registered using different instruments in different zones of the electromagnetic spectrum of wavelengths (Table 1).

The visible spectrum of electromagnetic oscillations with wavelengths from 0.4 to 0.7 μm is subdivided into different colors (Table 2).

Beyond the violet spectral region lies the ultraviolet, and beyond the red -- the infrared.

Aerospace methods for studying the earth's soil and agricultural resources are subdivided into photographic and photoelectronic. During recent years ever-increasing attention of researchers working in the field of study of natural resources has been devoted to the use of photoelectronic methods. On the basis of achievements in development of the latest technology these methods are finding ever-increasing application in such fields as geology, meteorology, agriculture, soil science, and others.

An aerial survey is a survey of the terrain (from an altitude as little as hundreds of meters to 20 km) executed from flight vehicles using different surveying instruments operating in different zones of the electromagnetic spectrum. At the present time an aerial survey also includes a photoelectronic survey. A space survey of the earth results in photographs and traces of the earth's surface taken from altitudes greater than 80-100 km from different flight vehicles: research rockets, artificial earth satellites, automatic orbital stations, manned space stations. Information concerning the earth's surface can be obtained from these flight vehicles as a result of visual observations, in the form of television images, photographs of the earth and data from photoelectronic apparatus.

We will examine different types of aerial and space surveys.

Types of Aerial Photographic Surveys of the Earth's Surface

An aerial photographic survey is a method for photographing of the earth's surface by an aerial camera which is mounted on an aircraft, helicopter or other flight vehicle.

The choice of equipment and instrumentation for carrying out an aerial survey of the soil cover is of great importance for obtaining spectrograms and aerial photographs with the best possibilities for interpretation. During recent years in our country IL-14 aircraft, specially re-equipped for the placement of aerial cameras, and most recently, also the AN-30, have been used for photographing the earth's surface.

Modern aerial cameras are classified on the basis of focal length, angle of view of objective and number of objectives. On the basis of focal length aerial cameras can be classified as short-focus (f to 150 mm), medium-focus (f from 150 to 300 mm) and long-focus (f above 300 mm). Short- and medium-focus (focal length) objectives have assumed the greatest importance for soil surveys, carrying out land surveying and for mapping purposes. In lowlands and slightly hilly territories it is desirable to use aerial cameras with a short focal length (50-100 mm). Super-wide-angle aerial cameras (50-70 mm) can give the best results in steppe and dry steppe zones in the territories of the plains bordering on the Black Sea, Sea of Azov and Caspian Sea, as well as in the lowland expanses of Kazakhstan with well-developed microrelief. Aerial cameras with a medium focal length (200 mm) should be used in mountainous and highly dissected territories with local relief of more than 150-200 m.

In a super-small-scale photographic survey (1:100,000-1:250,000) a comparative analysis of different types of aerial cameras with a short focal length indicated that for an aerial survey of different territories it is possible to recommend the TES-50 and 41/7.5 aerial cameras with focal lengths of 50 and 75 mm (Apostolov, Gorbatov, 1975).

In making a large-scale aerial photographic survey (about 1:10,000) it is recommended that use be made of an AN-2 aircraft and an AFA-39 aerial camera with a focal length of 100 mm. It is simple to service, is reliable in operation and makes it possible to obtain photographs with a high information content.

Table 1. Methods for Aerospace (Remote) Study of Soil Cover and Agricultural Crops (According to B. V. Shilin)

Photographic Survey				Infrared Survey			Radiothermal survey	Radar survey
Black-and-white	Color	Spectrozonal	Multizonal					
Visible		Visible-infrared		Infrared			Microwave	
				near	middle	far		
0.4-0.74 µm		0.4-1.2 µm		0.74-5.5 µm	5.5-20 µm	20-800 µm	0.8-100 cm	
$5\cdot10^8$ MHz				10^8 MHz	10^7 MHz	10^6 MHz	$2\cdot10^4$-$0.3\cdot10^3$ MHz	
Passive (reflected from soil surface or crops [solar radiation]; beyond 1.2 µm emission of features)				Passive (to 1.2 µm reflected solar radiation, then emission of soil-crops)			Passive	Active (radar) on carrier
Films				To 1.2 µm film, then photoelectric detectors			Antennas	
Day				Day and night				
Surface, µm							Several centimeters	Tens of cm and m
Weak				Atmospheric windows: 1.8-5.3 µm, 7.0-14.0 µm			Very weak	
Aerial or space photograph				To 1.2 µm aerial or space photograph; then image, signal			Antenna signal, curve, image	

Characteristic	Ultraviolet survey		Luminescent survey	Photoelectronic survey		
				spectrometric	TV	multispectral
Range of electromagnetic spectrum	Ultraviolet far	near	Visible	UV, visible, IR	Visible	Visible, IR
Wavelength (λ)	3000-100A	up to 4000A	0.4-0.74 μm	0.3-5.5 μm	0.4-0.74 μm	0.4-12.5 μm
Frequency	$1 \cdot 10^{9}$-$3 \cdot 10^{10}$ MHz	$8 \cdot 10^{8}$ MHz	$5 \cdot 10^{8}$ MHz			
Relationship of method to radiation source	Passive		Active source of radiation on carrier (secondary luminescence is excited in visible light)	Passive (reflected from soil or crops [solar radiation]; beyond 1.2 μm emission of features)		
Sensitivity of element (detector)	Photomultiplier	Films, photomultiplier	Photomultipliers		Detectors with electronic scanning	
Time of day in survey	Day		Night		Day	
Depth of survey					Surface, μm	
Nature of atmospheric absorption	Almost total	Strong	Weak			
Nature of collected data	Signal, curve, image	Air photo, signal, curve	Signal, image	Spectral brightness curves, image	Aerial or space photo, image, signal	

Table 2

Colors of Visible Spectrum of Electromagnetic Oscillations

Color	Wavelength, μm
Violet	0.40-0.44
Dark blue-violet	0.44-0.47
Dark blue	0.47-0.485
Light blue	0.485-0.50
Green-light blue	0.50-0.52
Green	0.52-0.55
Yellow green	0.55-0.57
Yellow	0.57-0.58
Orange-yellow	0.58-0.59
Orange	0.59-0.60
Red-orange	0.60-0.62
Red	0.62-0.70

On the basis of angle of view objectives are classified as wide-angle (with an angle of view from 80° or more), normal (45-75°) and with a small angle of view (from 40° or less, long focal length) (Table 3).

On the basis of the number of objectives aerial cameras are classified as single-, two- and multiobjective cameras. During recent years there has been a particular increase in the role of multiobjective aerial cameras employed in a multizonal survey in a study of natural resources, soil cover and the state of agricultural crops.

A set of light filters was used in carrying out a multizonal photographic survey in 1973. Data on some of these are given in Table 4. The materials obtained in this survey were used in our study.

The broad array of aerial survey photographic and photoelectronic apparatus carried aboard aircraft enables specialists in the field of study of the soil cover and agricultural crops to use materials from an aerial survey not only for the purposes of mapping, but also for study of the makeup of the composition and properties of soils and determining their fertility. These data make possible an approach to automation of the process of interpretation of the soil cover and agricultural crops with use of an electronic computer. In addition, the methodology used in a number of experiments carried out with aircraft is used when carrying out space investigations.

Types of Space Surveys and Equipment Used in Study of the Earth's Natural Resources

Table 3

Principal Characteristics of Aerial Camera Objectives

Type of objective	Focal length (f), mm	Relative aperture (1:n)	Image angle (2β),°	Resolution, lines/mm	
				at center	at edge
"Rodina-2"	55	1:8.2	133	35	12
"Russar-29"	70	1:6.8	122	30	10
"Russar-44"	100	1:6.8	105	36	23
"Russar-43"	140	1:6.8	85	36	20
"Russar-35"	200	1:9	65	53	32
"Tafa-3"	350	1:6	40	40	25
"Ortoniar-13"	500	1:7	35	40	25

The development of space technology and new methods and apparatus for remote sensing (together with an aerial photographic survey) and their successful application for scientific and national economic purposes have created the prerequisites for a new approach to study of natural resources, especially in the field of soil science and agriculture.

Table 4

Characteristics of Some Light Filters Used in an Aerial Survey in 1973

Light filter components	λ_{eff}, μm	Q coefficient	Thickness, mm
SZS-20, ZhS-16	0.499	9.4	8
SZS-22, ZhS-17	0.519	9.7	10
SZS-23, OS-12	0.587	8.2	10
ZhZS-18, KS-10	0.637	8.2	8
KS-17	0.683	43.7	5

The first visual observations of the earth's surface from space were made in 1961 by the cosmonaut Yu. A. Gagarin. G. S. Titov for the first time in history carried out a survey of individual natural features by camera. Visual observations from space were also made by other cosmonauts.

A great number of original photographs of the earth's surface was obtained in the USSR and in the United States as a result of flights of spaceships and artificial earth satellites. Black-and-white, color, and spectrozonal photographs at scales 1:200,000-1:2,500,000 and smaller have a clear image of the soil cover and agricultural fields.

The images of the earth obtained from space can be divided into two main groups: original space photographs and television images. The original photographs are characterized by high measurement and interpretation properties. In comparison with space photographs, a television survey has advantages with respect to frequency, repetition and regularity of collection of images of the earth's surface. However, television photographs are characterized by a lesser resolution.

In the Soviet Union photographing of the earth's surface from space, with the obtaining of original space photographs, was accomplished using hand cameras and photographic apparatus from the automatic stations "Zond-5," "Zond-7" and "Zond-8," the "Vostok," "Voskhod" and "Soyuz" spaceships and the "Salyut" orbital station. Photographing of the earth was carried out during flight of the "Voskhod-2" ship-satellite in 1965 during the emergence of A. A. Leonov into space.

During 1968 the "Zond-5" automatic station was used in obtaining the first global photographs of the earth from an altitude of about 90,000 km.

Table 5

Photographic Characteristics of Black-and-White Films

Type of aerial film	Толщина эмульсионного слоя, мкм 1	Светочувствительность, ед. ГОСТ 2		Contrast coefficient	Разрешающая способность, лин/мм 4	Сенсибилизация, нм 5	
		total	эффективная за светофильтром ЖС-18 3			maximum	limit
Isopanchromatic type 13	25	1900—2000	950—1000	1,6—2,1	70	670—680	700—720
Isopanchromatic type 15	15	800	400	1,7—2,3	85	670—680	710 —720
Isopanchromatic type 17	12	600	300	1,5—2,2	100	670—680	700—720
Isopanchromatic type 18	5	100	50	2,0—3,0	250	670—680	700—720
Isopanchromatic type 20	8	500—700	250—350	1,5—2,1	100	670—680	700—720
Isoorthochromatic type AS-1 with protective antiaureole layer	20	800	500	1,5—2,1	70	580—590	620—630
type RF-3 without antiaureole layer	20	800	500	1,6—2,1	70	580—590	620—630
Isoorthochromatic type 14	12	600	300	1,5—2,2	100	560—630	650
Infrachromatic I-740	—	600	150 (KC-14) 6	1,6—2,6	68	740—750	800—820
Infrachromatic I-760	—	400—800	100—200 (KC-14)	2,0—2,5	60—80	750—760	800—820
Infrachromatic I-840	—	—	240 (KC-14)	1,6	85	840	—

KEY:

1. Thickness of emulsion layer, μm
2. Light sensitivity, GOST units
3. Effective with ZhS-18 light filter
4. Resolution, lines mm
5. Sensitization, nm
6. KS-14

During the first docking of the "Soyuz-4" and "Soyuz-5" spaceships in orbit the cosmonauts Ye. V. Khrunov and A. S. Yeliseyev emerged into open space and carried out visual observations, still and motion picture surveys of the earth's surface. In accordance with the program, during the group flight of the "Soyuz-6," "Soyuz-7" and "Soyuz-8" manned spaceships observations were made and photographs were taken of the soil-vegetation cover and the nature of the geological-geographic features in different regions of the USSR.

A space survey was made for territories well studied in natural respects for the purpose of developing a method for using space photographs for studying the earth's natural resources. Another important aspect of the program was a study of the spectral brightness and contrasts of the earth's surface in the visible zone of the spectrum (steppe, desert, forested areas, lakes), necessary for determining the optimum conditions for the photographing of natural features. As indicated by K. Ya. Kondrat'yev, et al. (1971), by having spectra of natural features obtained from space it is possible to differentiate types of soils, determine the state of agricultural crops and solve other problems.

In mid-June 1970 the cosmonauts V. I. Sevast'yanov and A. G. Nikolayev flew aboard the "Soyuz-9" spaceship. During the flight they made observations of agricultural fields and the soil cover over the territory of the Sal'sko-Tsimlyanskiy and other regions of the USSR. In accordance with the program, they carried out photographing of the earth's surface in the Northern Caucasus, in the neighborhood of the Caspian and Aral Seas, Kazakhstan and Western Siberia. Simultaneously with the survey from space, these same features were photographed from aircraft (Sevast'yanov, 1972). The cosmonauts were able to discriminate sown areas with respect to the variety of agricultural crops and the phenological stage of development. The survey from the "Soyuz-9" was made using a yellow light filter on small-format panchromatic film using a hand camera with the frame measuring 6 x 6 cm from an altitude of about 230 km at a scale of about 1:7,500,000, with a resolution of 200-300 m in the terrain.

The long-lived orbital station "Salyut-1" was launched in 1971. It was a complex manned space vehicle making it possible to carry out a broad complex of scientific experiments in circumterrestrial space. The station was launched into orbit at an altitude of 240-260 km with an inclination of 51.6° to the equatorial plane and with a period of revolution about the earth of 89 minutes.

After the docking of the "Salyut-1" with the "Soyuz-11" spaceship the crew carried out a spectral survey of characteristic features on the earth's surface. At the same time, an aerial survey was made of these same regions from specially outfitted aircraft of an expedition of Leningrad State University and the USSR Academy of Sciences. During this space flight for the first time there was a continuous reconnaissance photographic survey along global trajectories running along and across the earth's latitudinal physiographic zones. The survey was made in June with an AFA-31s aerial camera without a light filter with a focal length of 31.6 mm (frame measuring 60 x 70 mm). The photographs were taken using isopanchromatic film type 17. The scale of the photographs was about 1:8,000,000 with a resolution in the terrain of 250-300 m. The area covered by one photograph is about 250 km^2. These photographs, due to their great coverage, are of great importance for small-scale special mapping.

The beginning of a multizonal survey of the earth's surface from space is associated with the flights of the manned spaceships "Soyuz-12" and "Soyuz-13" in 1973-1974. The survey was made using the special LKSA-3 9-objective camera in which three photofilms were used simultaneously. Further visual observations and photographing of the earth's surface for the purpose of rational use of terrestrial resources in the interests of the national economy were carried out during subsequent flights of spaceships, the orbital station "Salyut-3," launched in June 1974, and during the "Soyuz-Apollo" joint flight.

Much experimental photographic material from space, necessary for study of the earth's natural resources, was obtained as a result of the "Salyut-4" flight. Photographs for a considerable area were obtained for the territory of our country, primarily in the middle and southern latitudes. Spectrographic measurements of individual geological-geomorphological formations on the earth's surface were made. The "Salyut-5" was launched in 1976, and for joint experiments with it, the "Soyuz-21."

The new qualitative characteristics of photography of the earth's surface from space by means of long-term orbital stations of the "Salyut" type are as follows: 1) the possibility of carrying out a great volume of photography with coverage of different survey seasons; 2) repeated surveying of one and the same natural features; 3) use of different cameras and different films, making it possible to carry out a survey at different scales and in different spectral zones; 4) choice of the optimum atmospheric conditions for a space survey.

The flight of the "Soyuz-22" spaceship took place in September 1976. It carried the MKF-6 multizonal camera, developed by USSR and East German specialists. Photographs of a number of sectors of the earth's surface were obtained using this camera in six spectral zones with a high resolution. During the time of the work photographs were taken in the visible and IR spectral zones in the range from 0.46 to 0.89 μm. With a flight altitude 250-260 km a film measuring 55 x 80 mm covers an area of 115 x 165 km, that is, about 19,000 km^2. In 1978, during the flight of the "Salyut-6" orbital station, a multizonal survey of the earth was continued using the MKF-6M camera.

In addition to direct photographing of the earth from space, another important direction which is now experiencing vigorous growth and development is a television space survey. In a television survey from a satellite the photoimage of the earth's surface is fed to a vidicon and then is sent through a radio channel to surface TV receivers, from whose screens the image is photographed, and a screen photograph is obtained. Since the time for exposure of one frame by television systems is 1/25 sec or less, and the time of its transmission is 200-400 sec, the need arises for using videomagnetic memory systems aboard the satellite. It is also possible to store images on a film. Such systems are known as phototelevision systems.

In comparison with photographs from space, television photographs have a lesser resolution (from 80-100 m to several kilometers); their metric properties are also poorer due to the nonlinearity of scanning, etc. Whereas at the present time in the actual study of the earth's natural resources from space photomethods, with the best resolution, play an important role, in the long run scanning systems with the transmission of information from satellites via radio channels will have ever-greater importance. The role of scanning systems will increase still more if it is taken into account that in a photographic survey of the earth's surface the deliveries of materials to the earth are considerably less routine. Precisely the routineness of collection of information on the state of terrestrial resources is one of the basic and fundamental characteristics of a survey from space.

In our country a television survey for national economic purposes is also made from meteorological satellites, which makes it possible to obtain routine information on the state of weather on the earth and the characteristics of the underlying surface.

Satellites of the "Cosmos" series were used in 1963 in testing the corresponding television systems and electrotechnical devices. In 1966 the "Molniya-1" satellite was used in the USSR for obtaining a TV image of the earth from a distance of 40,000 km. Later during flight of one of the satellites of the "Cosmos" series photographs were taken of the cloud cover and the underlying surface in the infrared in the spectral range 8-12 μm.

In 1967 artificial earth satellites of the "Cosmos" series were launched for forming the unified "Meteor" space system. The satellites were put into circular orbits with an altitude of 625-630 km. During 1977-1979 routine information on the state of the earth's surface was regularly transmitted from experimental "Meteor" satellites in four zones of the visible and infrared spectral ranges.

In the United States flights of the "Mercury" (1961-1963), "Gemini" (1964-1966) and "Apollo" (1968-1971) spaceships made it possible to obtain hundreds of space photographs of different regions on the earth (most of the photographs were color photographs). The survey was made with hand small-format cameras.

Since 1960 television images of the earth's surface have been regularly transmitted from American meteorological satellites. The first eight satellites of the "TIROS" series were launched in 1960-1965.

Satellites of the ITOS series (ITOS -- Improved TIROS) were launched in 1970 into a solar-synchronous polar orbit with an altitude of about 1,400 km (with a period of revolution 115 minutes). They carried TV cameras for transmission of images of the earth at a real time scale (with a resolution of about 1 km) and in the record (resolution 3.2 km).

The United States meteorological satellite, which is of interest because its materials can be used in interpreting the earth's surface, is the "Nimbus." The latest satellites of the "Nimbus" series carry a microwave probe for determining soil moisture content.

The first specialized satellite for studying the earth's natural resources (ERTS-1 -- Earth Resources Technological Satellite) was launched in July 1972 in the United States. The ERTS-2 was launched in January 1975. These satellites have now been given the name "Landsat." A third satellite was launched in 1978. The satellites were put into a solar synchronous orbit with an altitude of about 910 km with a period of revolution of 103 minutes. The selected orbit ensures an almost constant solar altitude above the horizon $\sim 35°$, that is, identical illumination conditions for each region. The satellites make 14 revolutions per day and each 18 days there is a possibility for a repeated survey of one and the same sectors of the earth's surface.

The ERTS-2 was launched in such a way that the frequency of recurrence of a survey of one and the same sector of the earth was 9 days, which made it possible to observe the dynamics of the soil-vegetation cover and the development of agricultural crops, to study the soil-vegetation cover in different seasons of the year, to select cloudless periods of the survey in order to have a better image of the soil-vegetation cover in dependence on weather and seasonal conditions of the survey, etc. The satellite carried a multichannel optical-mechanical scanning television camera, the MSS (Multi Spectral Scanner), an instrument scanning in the visible and IR spectral regions: 0.5-0.6, 0.6-0.7, 0.7-0.8, 0.8-1.1 μm. The camera angle of view is 11.5°; in scanning from an altitude of 910 km there is coverage of a zone with a width of 185 km and the resolution in the terrain is 70-80 m.

Photographs with the MSS multizonal scanner are of interest for different branches and departments and are effective when using such automatic satellites for studying the earth's natural resources.

In May 1973 the "Skylab" orbital station was launched into an orbit close to circular, with an altitude of 435 km and a period of revolution of 93 minutes. One of the scientific objectives of operation of this station was an investigation of the earth's natural resources.

Thus, artificial earth satellites, spaceships and orbital stations are used for studying the earth's natural resources. Special automated satellites for studying the earth's resources have been developed and used in recent years. Photographic and television cameras are among the instruments widely used on space vehicles. Both space multizonal photography and multispectral scanning of the earth's surface from space are successfully developing. Infrared and microwave apparatus is also used in space surveys.

The altitudes for a space survey of the earth's surface can be divided into four groups:
1) great altitudes -- 10,000-100,000 km -- surveys from interplanetary automatic stations of the "Zond" type;
2) medium altitudes -- 500-1,500 km -- surveys from natural resources and meteorological satellites;
3) low altitudes -- 200-400 km -- surveys from manned spaceships of the "Soyuz" type, long-lived orbital stations of the "Salyut" and "Skylab" type, and experimental satellites;
4) very low altitudes -- less than 200 km -- surveys from experimental satellites.

With respect to the area of coverage of the soil cover by a single space photograph we propose that photographs be classified as:
a) global -- transmission of the image of individual continents or the earth as a whole (for example, photographs of the earth from the automatic station "Zond-5");
b) macroregional -- images of major parts of the continents with an area of 100,000 km^2 or more (photographs from NOAA, and others);
c) mesoregional -- with coverage of geographic regions with an area of tens of thousands of square kilometers, for example, the multizonal survey with the MKF-6 camera from the "Soyuz-22" and the "Salyut-6" from an altitude of 250-260 km in six spectral zones (from 0.46 to 0.89 μm) with an area of coverage of one photograph of 19,000 km^2; a multispectral scanning survey with the MSS camera from the ERTS ("Landsat") from an altitude of 910 km in four spectral zones (0.5-0.6, 0.6-0.7, 0.7-0.8, 0.8-1.1 μm) with an area of coverage of one photograph of 35,000 km^2;
d) regional -- with a coverage of individual regions (landscapes) with an area less than 1,000 km^2.

Depending on the survey scale space photographs can be classified as large-medium-scale (greater than 1:100,000), medium-scale (1:100,000-1:900,000), small-scale (1:1,000,000-1:9,000,000); generalized (1:10,000,000 - 1:100,000,000).

In the present stage in the development of space technology the resolution (R) of the space photographs, dependent on altitude (H) of the survey, focal length (f) and resolving power of the receiving instrument

$$R = f \frac{H}{r}$$

can be subdivided into:
a) tens of kilometers -- for radar images, the IR range of Soviet and American meteorological satellites, surveys from interplanetary automatic stations of the "Zond" type or satellites in high orbits;

b) a few kilometers -- for television photographs in the visible range from meteorological satellites;
c) hundreds of meters -- for photographs taken with hand cameras and also medium-focus cameras from spaceships and satellites;
d) tens of meters -- for high-quality ordinary and multizonal cameras of the MKF-6 type and also multispectral scanner systems.

Materials from Aerospace Survey and Instruments for Interpretation

As has been noted, the materials from aerial and space surveys can be used in studying the soil cover and individual properties of the soil, for determining the yield of agricultural crops and soil fertility, and also as a cartographic base for the compilation of soil maps at different scales. It is possible to use black-and-white, color and spectrozonal negatives, double negatives and double positives obtained in the course of aerial and space surveys; black-and-white, color and spectrozonal aerial and space photographs obtained by the contact method or by enlargement on the average by 4^x–5^x; reproductions of preliminary compilations, photomosaics, photoplans and photomaps. During recent years increasing importance has been assumed by aerial and space materials from a multizonal survey, television photographs, materials from multispectral scanning systems, traces obtained from ultraviolet, infrared and microwave radiometers, and radar photographs of the soil cover and plantings of agricultural crops.

In this section we will examine the importance of materials obtained using photographic systems; others will be examined in describing new photoelectronic methods for investigating terrestrial resources.

Black-and-white, color, spectrozonal and multizonal negatives and double positives are of great importance in studying the soil cover and the condition of agricultural crops. Their role has especially increased in connection with the use of multizonal surveys of the earth's surface. The principal photographic characteristics of black-and-white aerial films are given in Table 5.

A black-and-white panchromatic film and a yellow light filter were successfully used in surveys from the "Soyuz-9" spaceship. In surveys from the "Salyut-1" orbital station successful photography was carried out using an isopanchromatic film (type 18) with a yellow light filter.

When making a multizonal survey from the "Soyuz-12" spaceship the photography was with different light filters on fine-grained isopanchromatic aerial film (type 17), coarse-grained isopanchromatic motion picture negative film KN-3 and coarse-grained infrachromatic aerial film I-840.

In multizonal photography of desert and semidesert zones of Kazakhstan in February from the "Salyut-4" orbital station use was made of black-and-white films: isochromatic of the type AS-1, isopanchromatic of type 17 and infrachromatic of type I-840. A comparison of one and the same soils and natural features surveyed from space on different films indicated that moistened sectors of the Muyunkum sands and the eastern part of the Betpak-Dala desert, ancient valleys in the territory of the Betpak-Dala and contaminated territories in the region of Lake Baykal are interpreted most clearly from photographs obtained from infrachromatic film and less clearly from photographs obtained with isochromatic film (Table 6).

In the United States, when carrying out a multizonal survey from the "Apollo-9" spaceship, the photography of the earth's surface was taken on panchromatic and infrachromatic film. During the period of operation of the "Skylab" orbital station black-and-white panchromatic film was used in two surveying cameras of the multispectral photographic apparatus S 190, whereas infrachromatic film was used in two others covering the infrared spectral zone.

When making a super-small-scale aerial survey of the earth's surface Apostolov and Gorbatov (1975) recommend the use of black-and-white films: for lowland regions -- types 17, 18, 20, 27, 28, for mountainous regions -- types 17, 20, 25, 33.

Isoorthochromatic black-and-white aerial films of the RF-3 and AS-1 types are recommended for aerial surveying in the yellow-green spectral zone.

In addition to isopanchromatic films, the infrachromatic films I-740, I-760 and I-840 are of great importance for studying the soil cover.

A comparative analysis of the soil cover image on aerial photographs taken with isopanchromatic and infrachromatic films indicated (Fig. 1) that on infrachromatic photographs it is considerably easier to see the boundary contrast of chernozem and alluvial soils; dark gray, gray forest and soddy-meadow soils. On isopanchromatic photographs these soil differences are seen poorly or not at all (Table 7).

The use of infrachromatic film for soil purposes can be recommended for the detection of soils with a different degree of moisture content, gleyey, swampy, irrigated soils. This film is effectively used for discriminating plowed sectors amidst virgin land with natural vegetation, for the interpretation of areas of alluvial (floodplain) soils.

However, when using infrachromatic film it must be remembered that in comparison with isopanchromatic film there is a deterioration of image development in shaded sectors. In order to reduce the influence of shadows it is desirable that the infrachromatic survey be made at about 1200 hours with a high solar altitude.

B. V. Vinogradov (1966) mentions the limited possibilities of use of this film in studying the soil-vegetation cover of arid zones. In a survey with this film the dry sectors of brown desert-steppe soils, solonetz and other soils merge with vegetation on the photoimage.

Table 6

Boundary Contrast (Interpretability) of Soils and Other Phenomena on Space Photographs Taken from "Salyut-4" on Different Films

Soils or other phenomena	Difference in levels of gray tone		
	isochromatic type AS-1	isopanchromatic type 17	infrachromatic I-840
Typical gray soils and alluvial solonchak-like soils with participation of meadow-gray soils	8	8	10
Gray-brown desert soils and gray takyr-like soils with participation of takyrs	9	8	11
Gray-brown desert soils with different moistening	0	3	8
Ancient valleys of Betpak-Dala	2	4	6
Moistened sectors of soils and sectors covered by snow	9	10	15
Territories contaminated by industrial wastes, snow-ice cover	3	9	15

Note: In this and subsequent tables data on the boundary contrast (in relative units) were obtained using the "Kvantimet-720" image analyzer, which from black to white discriminates 64 gray tone levels.

Table 7

Boundary Contrast (Interpretability) of Soils on Aerial Photographs Taken With Different Films

Name of boundary soils	Difference in levels of gray tone	
	isopanchromatic	infrachromatic
Leached chernozems and gray forest gleyey	3	7
Leached chernozems and alluvial-meadow	1	8
Leached chernozems and alluvial-moist-meadow	3	10
Alluvial-meadow and moist meadow	2	2
Dark gray and gray forest	3	2
Dark gray and gray forest gleyey	7	14
Gray and gray forest gleyey	4	11
Dark gray forest and soddy-gleyey	3	20
Gray forest and soddy-gleyey	7	12

Table 8

Photographic Characteristics of Color and Spectrozonal Aerial Films

Type of aerial film	Total (for color aerial films) and effective (for spectrozonal films) light sensitivity GOST units	Contrast coefficient	Resolution, lines/mm	Light sensitivity balance	Contrast balance
Color negative (TsN-3)	180	0.8–1.2	58	2.5	0.15
Color negative (DS-5)	60	0.8–1.2	58	---	0.15
Spectrozonal (SN-2M) with light filter:					
ZhS-18	200–300	1.7–2.6	58	2.6	0.4
OS-14	150				
KS-14	100				
	600	2.7	63	2.6	0.4
Spectrozonal (SN-6M)(with OS-14 light filter)	200	---	100	---	---
Spectrozonal (SN-4) (with ZhS-18 light filter)	200	---	---	1.0	---
Spectrozonal (SN-5) (with ZhS-18 light filter)	150	1.5–2.0	68–72	3.0	0.4
Spectrozonal (SN-23) (with ZhS-18 light filter)	200	1.5–2.0	68–72	3.0	0.4

Table 9

Spectral Zones of Effective Light Sensitivity of Color and Spectrozonal Aerial Films (According to A. [illegible]. Iordanskiy, 1967)

Type of aerial film	Layer position	Type of sensitizing of emulsions	Спектральная зона эффективной светочувствительности, нм [1]	Light filters	Image color
Color negative (TsN-3)	Upper	Unsensitized	400—480	—	Yellow
	Middle	Orthochromatic	500—580	—	Purple
	Lower	Panchromatic	600—680	—	Light blue
Spectrozonal (SN-2M)	Upper	Infrachromatic	670—800	ЖС-18 [2]	Bluish-green
			»	ОС-14 [3]	
			»	КС-14 [4]	
	Lower	Panchromatic	510—670	ЖС-18 [2]	Purple
			570—670	ОС-14 [3]	
			—	КС-14 [4]	
Spectrozonal (SN-6M)	Upper	Infrachromatic	650—800	ОС-14	Bluish-green
	Lower	Panchromatic	570—650		Purple
Spectrozonal (SN-8)	Upper	Infrachromatic	650—800	ОС-14	Purple
	Lower	Panchromatic	570—650		Bluish-green
Spectrozonal (SN-4)	Upper	Orthochromatic	500—600	ЖС-18	Purple
	Lower	Panchromatic	570—690		Light blue
Spectrozonal (SN-5)	Upper	Infrachromatic	670—800	ЖС-18	Bluish-green
	Lower	Orthochromatic	500—600		Purple
Spectrozonal (SN-23)	Upper	Infrachromatic	670—800	ЖС-18	Light blue
	Middle	Panchromatic	580—680		Purple
	Lower	Orthochromatic	500—600		Yellow

KEY:

1) Spectral zone of effective light sensitivity, nm
2) ZhS-18
3) OS-14
4) KS-14

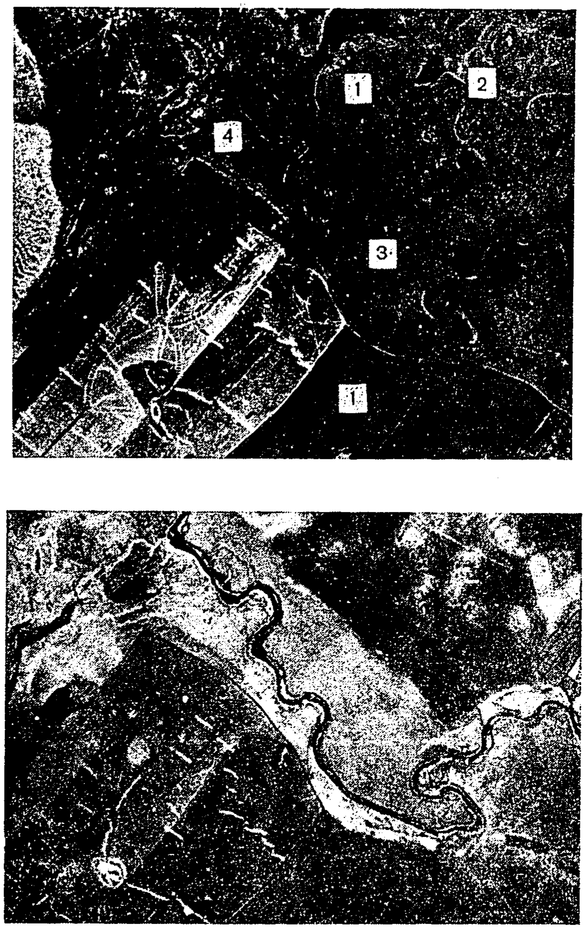

Fig. 1. Aerial photographs of one and the same territory obtained using different aerial films. At top -- isopanchromatic; at bottom -- infrachromatic (1 -- leached chernozems; 2 -- gray forest gleyey soils; 3) alluvial-meadow; 4) alluvial-moist meadow).

This film can be used successfully in soil melioration work.

Color and spectrozonal aerial films. In the study and proper interpretation of the soil cover color and especially spectrozonal aerial films have broader possibilities. The human eye perceives the differences in chromatic tones tens of times better than the tonality of a gray scale. The use of the color differences of the soil-vegetation cover in the case of a survey on color aerial film considerably broadens the possibilities for soil interpretation.

Among the color multilayer films there are two principal types: color three-layer aerial films which reproduce the soil-vegetation cover in natural (or nearly natural) colors and spectrozonal two- or three-layer aerial films with an image of the earth's surface in conventional colors.

Color reversible three-layer aerial films for neutral and transformed color transmission of the earth's surface are widely used abroad.

Modern color films, both in our country and abroad have a quite high sensitivity, low distortion, good color balance and resolution (Table 8). They can be used successfully not only for a qualitative, but also quantitative interpretation of the soil cover and plantings of agricultural crops but are inferior to black-and-white aerial films with respect to the economy of photoprinting.

TsN-3 color negative film is an improved TsN-1 type with respect to color transmission, with a higher resolution and light sensitivity. This is a three-layer film; the arrangement of its layers, the type of sensitizing of the emulsion and the spectral zones of effective light sensitivity are indicated in Table 9.

Good results were obtained in the USSR in a survey from space using SN-6M and SN-8 spectrozonal films (zones of sensitivity 570-650 and 650-800 nm respectively). A somewhat worse image of the earth's surface was obtained in a space survey on TsN-3 color film (zone of sensitivity 450-730 nm) with natural color transmission.

Color natural film of the Kodak Ectachrom MS type and color IR Kodak-Ectachrom Infrared film was used during flights in the American spaceships "Mercury," "Gemini" and "Apollo" for extensive survey work.

In the irrigated zone of the Colorado River (United States) color IR film was also successfully used in discriminating agricultural fields up to 20 hectares in area, occupied by different crops, from the red and gray-green color. A red color was characteristic of fields with alfalfa and a gray-green color is characteristic of fields with harvested cotton. In a mountainous area a brown-red color corresponded to coniferous forests (Pinus ponderosa) and a light red color corresponded to oak forests.

In the study of soils with different moisture content (from 2-8 to 30-34%) it was established that the best results in determining the moisture content of plowed soils were obtained in an aerial survey from an altitude of 600-1,200 m on color IR film (Sewell, Parks, 1972).

The use of negatives and photometric instruments makes it possible to carry out quantitative measurements of the photoimage of the soil cover, based on determination of the density of blackening of the analyzed negatives. It is now acknowledged that the photometric approach to the study of soils from negatives is one of the promising means for automation of interpretation of the soil cover. The basic studies on use of photometric instruments are now being made using black-and-white negatives. However, there are investigations of the use of color and spectrozonal images for these purposes.

Black-and-white, color, spectrozonal and multizonal contact or enlarged aerial and space photographs are of basic importance for visual-instrumental interpretation of the soil cover and its mapping.

In accordance with the type of aerial survey cameras used the common size of aerial photographs is 18 x 18 cm; 24 x 24 cm; 30 x 30 cm; for multizonal cameras it is 7 x 7 cm. The photographs taken by a multispectral scanning system can have the form of strips. In our country a size 18 x 18 cm is used for measurement and cartographic purposes and the principal photogrammetric instruments have been developed for this size; abroad a size 24 x 24 cm is used for this purpose. Aerial photographs measuring 30 x 30 cm are convenient for interpretation of the soil cover.

A considerable economic effect can be obtained when using photographs enlarged by $3\text{-}4^x$ in comparison with the original. According to data published by American specialists, a photographic enlargement of the space photographs obtained with the ERTS for the purpose of facilitating their soil interpretation and increasing the information yield is dependent on the negative quality and after a 5^x enlargement gives virtually no increase in information.

The scale of the photographs is determined using the formula $1/m = f/H$, where f is the focal length of the objective, H is survey altitude.

Near-vertical aerial photographs have a normal end lap of 60% and a side lap of 40%, which ensures inspection of stereopairs with stereoscopic instruments. Aerial or space photographs are of importance for soil mapping because they are a good geographic base. The great number of details appearing on aerial photographs make possible a more precise identification of the location of soil profiles and orientation in the terrain. Aerial or space photographs constitute completely objective material on natural conditions and the soil cover, which is obtained using photographic or phototelevision instruments.

It is particularly important that on aerial and space photographs there are a number of direct and indirect indicators necessary in interpretation of the soil cover. This property makes it possible to carry out the office interpretation of soils and with the development of knowledge concerning the image of different soils on photographs and the development of soil keys it is possible to reduce the time-consuming field work for study of the soil cover gradually to a minimum.

The reproduction of a preliminary compilation is a mandatory supplement to aerial photographs. These are prepared from aerial photographs (contact prints) and make it possible to draw conclusions concerning the correctness with which the aerial survey was made. On the reproductions of the preliminary compilation it is mandatory to indicate the number of the sheet, the number of the rectangle, the names of individual populated places, rivers, lakes and some other features. This information makes possible a rapid determination of the region and the numbers of the aerial photographs required for the work.

Photomontages are an assembly of unrectified aerial and space photographs (that is, the use of photographs without elimination of existing distortions).

A photoplan is a plan of the terrain (mosaiced montage), assembled from rectified aerial and space photographs. It has a coordinate grid. On photoplans the relief is frequently drawn in with contour lines. Accordingly, photoplans are valuable material for studying the soil cover and its mapping. We note that when photoplans are available there is no need for photomontages.

Photomaps (black-and-white and color) are the most valuable base for carrying out soil mapping. They constitute polygraphically reproducible photoplans on which contour lines are used in plotting local relief, whereas hachures are used for representation of the topographic necessary for the soil survey. In comparison with topographic maps photomaps provide a saving, according to preliminary computations, up to 15% of the cost of work on a specialized survey (Gol'dman, 1972).

Instruments for interpreting soils and agricultural crops. The visual-instrumental method for the study of photographs is the most promising for soil interpretation. It provides for the extensive use of photometric and photogrammetric measurement instruments under field and office conditions.

Depending on their purpose, interpretation instruments can be classified as enlargement, measurement, stereoscopic, microphotometric and automatic systems for readout of the image.

Among the magnification instruments extensively used in the soil interpretation process are monocular lenses with different magnifications. Those with 2^x and 4^x are most widely used.

The measurement instruments include parallaxometers, parallactic plates, proportional dividers, etc. In the mapping of soils the use of proportional dividers is of great importance for eliminating a noncorrespondence of scales (between the photograph and map) in the transfer of special content from the interpreted photographs onto topographic maps or land surveying plans. Among the measurement instruments used in the interpretation of the soil cover an important role is played by MF-4 and IFO-451 microphotometers and among the foreign instruments -- a high-speed microphotometer with a contiguous stand and a compensation automatic recorder produced by "Karl Zeiss" in the GDR and others. The use of these instruments for measuring optical densities of aerial photograph negatives makes it possible to ascertain the nature and individual properties of soils in the analyzed territory. The "Macbeth" TR-527 instrument (United States) makes it possible to determine the density of negatives and positives with an accuracy 0.02D.

Among the stereoscopic instruments are stereoscopes of different makes, stereometers, interpretoscopes, the SP-2 stereoscope-pantograph for the transfer of features, and universal stereophotogrammetric instruments making it possible to obtain an image of the relief, measure it and draft it in contour lines, as well as to transfer soil areas from photographs to the map.

Among the automated systems for image readout are the "Kvantimet-720" ("Quantimet-720") optical-electronic instrument produced by "Metal Research" (Great Britain), which can be used successfully in studying the photoimage of the soil cover on aerial and space photographs.

Connected to the "Kvantimet-720" instrument is an epidiascope, used in obtaining images from aerial and space photographs, diapositives and films by means of transmitted and incident light with a dark field. Scanning devices -- vidicon and plambicon -- transform the image into electric signals for reception by the instrument detector. These devices have been developed for the precise analysis of images and have digital control of scanning. The results of measurements, repeated 16 times, have an accuracy to 1%.

Among the processing instruments necessary for the computerized interpretation of multizonal photographs we note the "P-1700" "Photomachine" developed by "Optronics International" in the United States, making it possible to carry out rectification of the photographic image and construct maps of isodensity lines for the forest and soil cover and for agricultural crops (Sukhikh, El'man, Bogachev, 1978).

The ISI electronic system (International System Incorporated) makes it possible to carry out rectification on the basis of densities for both integral and a series of multizonal aerial and space photographs.

In the synthesis of a black-and-white or color image from multizonal photographs it is possible to use MSP-4 multizonal analyzers produced by "Karl Zeiss Jena" (GDR), or the MSV-300 produced by the "Konon" Company (Japan), whereas the "Phosdak-1000" system produced by the "Kimoto" Company (Japan) and others can be used in transforming soil information from color densities.

[redacted]

Chapter 3

THEORETICAL PRINCIPLES OF INTERPRETATION AS A SOIL STUDY METHOD

A study of the problems related to the interpretation of aerospace materials is of the greatest interest among the complex of aerospace work for the surveying of land resources by soil scientists and a whole series of other specialists.

The Russian term for "interpretation" (deshifrirovaniye) is a derivative from the French word "dechiffrer" -- to analyze, unravel. In both English and Russian the corresponding term is "interpretation." During recent years the corresponding Russian term "interpretatsiya" has been used as a synonym for "deshifrirovaniye."

Originally interpretation was carried out for military-topographic purposes. However, beginning in the 1920's, with the development of civil aerial surveying, the interpretation of aerial photographs began to acquire a special character. In addition to topographic interpretation, forest, geological, soil, geobotanical, hydrological, agricultural and other types of special interpretation of aerial photographs began to develop. At the present time the soil cover is being interpreted from space photographs.

By the term "soil interpretation" is meant the method for studying the soil cover from its image obtained as a result of aerial or space surveys.

At the very dawn of development of aerial surveying A. Ye. Fersman wrote that an aerial survey does not characterize any one phenomenon, but different aspects of the landscape. It puts into the hands of the researcher a dialectic method which in the study of each feature makes possible a determination of its relationships to others. In this respect a study of the soil cover from aerial or space photographs is a clear example of use of the dialectic method.

N. G. Kell' emphasized that the interpretation of aerial photographs is a multifaceted process and no facet of this process can be separated from that branch of research in which it is manifested (Kudritskiy, 1973).

L. A. Bogomolov (1976), L. M. Gol'dman (1960), G. V. Gospodinov (1961) and L. Ye. Smirnov (1976) define interpretation as a method for studying terrain from its image on photographs, as a process for revealing the diverse content of photographs, based on an analysis of the interpretation criteria and a knowledge of their properties.

General Principles of Soil Interpretation

The interpretation process, from the point of view of knowledge and logic can be subdivided into a number of basic stages. I. S. Komarov, V. F. Rubakhin, L. T. Safronov (1967) indicate that with respect to structure the interpretation process consists of interpretation of individual features from aerial photographs and interpretation of situations. Three stages can be discriminated in interpretation: detection, identification and evaluation. A number of researchers call the third stage "interpretation"; however if the feature does not show up on the aerial photograph the interpretation process begins with identification. L. Ye. Smirnov (1967) defines the third stage of interpretation as the forming of judgments concerning individual features, phenomena and the terrain as a whole. V. F. Rubakhin (1966) ends the third stage in an evaluation of the results of identification of individual features and as an independent final section discriminates the process of real interpretation of situations from the aerial photograph, that is, there is a transition from the identification of one feature to another, from the identification of simple features to complex ones.

L. M. Gol'dman, R. I. Vol'pe (1968) also divide the interpretation process, on the basis of psychophysiological principles, into three stages: 1) visual perception of the studied features; 2) formulation of concepts (taking into account the conditions for carrying out the aerial survey) concerning the investigated territory and 3) a conclusion and description of the essence of the interpreted features.

A number of foreign authors (Buringh, 1960; Vink, 1968) include the following under the term photointerpretation: 1) recognition and identification of features appearing on photographs; 2) their analysis; 3) deduction, whose role is limited and can be used in the extrapolation and interpolation of data.

According to Buringh (1960), the terms recognition and identification take in obtaining the most complete and clearest idea possible from the photograph. Some foreign authors use the term photoreading instead of identification.

M. Girard (1972), in examining the problems involved in the soil interpretation method, discriminates three stages: 1) identification, that is, determining the relationships between the feature and its image on the photograph; this correspondence is not always expressed clearly for soils; 2) recognition, which essentially involves drawing of conclusions concerning the soil cover on the basis of knowledge concerning the morphology of soils and the peculiarities of their formation; 3) interpretation provides for establishing the interrelationships between soils and soil-forming factors.

In the interpretation of features, including the soil cover, it is necessary to take into account the initial level of interpretation. It is dependent on the level of training and capabilities of the interpreter and also the availability or nonavailability of interpretation keys.

A. P. A. Vink (1968) points out that the term identification or photoreading must be defined as a method for studying the aerial photographic image, which is based on a direct study of the features.

The soil, as a natural feature having a definite structure of the genetic profile and different soil horizons, does not show up on aerial photographs. On such photographs we see indices only of the surface horizon. However, this main surface horizon is genetically related to the entire soil profile. Accordingly, by analyzing the image of the surface horizon on aerial and space photographs in most cases it is possible not only to determine and interpret soil boundaries and changes, but also (in field investigations when samples are available -- soil interpretation keys or soil maps) to determine the soil cover.

According to B. B. Polynov, all soil horizons are paragenetic, that is, interrelated in their origin. On this basis, asserts Yu. A. Liverovskiy, (1962), the properties of the upper horizon can serve as indicators for determining the genetic category for the entire soil.

The relationship of the volume of field and office interpretation is of considerable importance in this stage of development of the soil interpretation method. Whereas during the first period of study of the soil cover with the use of material from an aerial photographic survey the role of field interpretation was fundamental, with the development of aerial methods, with the use of new equipment, with the broadening of knowledge concerning the peculiarities of the photoimage of soils on different films and for different seasons of the year, with the development of soil interpretation keys and with use of multizonal photographs there is a marked increase in the role of preliminary office interpretation of soils. Without question, in the future with the development and improvement of aerospace (remote) methods for investigating the environment the role of office interpretation will increase to the point of automated computer analysis of the soil cover and plantings of agricultural crops on the basis of aerospace photographs and trace data (when soil-agricultural interpretation samples are available).

During recent years three principal methods have stood out clearly in the problem of interpretation of photographs (Zonn, 1975). The first method, prevailing broadly until recently, is the visual interpretation method. The essence of this method is that recognition of the soil cover is based on experience and the ability of specialists to use direct and indirect criteria for soil interpretation. Its shortcoming is the descriptive approach to soil and agricultural resources and a definite subjectivity.

At the present time it is being replaced by the visual-instrumental method, in which, on the one hand, there is the most complete use of the logical inferences of the interpreter, and on the other hand, a quantitative analysis of the photoimage and interpretation of the soil cover. Visual-instrumental interpretation as an objective quantitative method for study of aerial and space photographs is based on the broad use of such measurement instruments in the practice of soil and agricultural research as microphotometers, densitometers and optical-electronic image analyzers.

A third method, which is in the stage of initial experimental investigation, is related to automation of the process of interpretation of photographs. It provides for the transformation of the photoimage of the soil cover and agricultural fields and the statistical processing of the filtered images. For example, in a soil melioration description of the territory of the dry steppe zone use was made of optical-structural machine analysis, which is a method for generalized (statistical) analysis of the morphological structure of the feature carried out in the optical range (Kozlovskiy, et al., 1975). Digital methods in the processing of aerial and space information are being developed most intensively in the Soviet Union and in the United States. They provide for the development of equipment, input of data on the image into an electronic computer, methods for its storage and extraction and creation of mathematical support for the processing of information (Lur'ye, Tishchenko, 1966).

In a report at the Eighth International Mapping Conference (Bel'chanskiy, et al., 1976) it was pointed out that three problems are timely among the principal directions in the development of methods for the digital automated processing of images: 1) processing and formalization of videoinformation; 2) automation of interpretation of photographs with the use of an electronic computer or optical-electronic instruments; 3) formulation of mathematical models in the plotting of predictive maps.

A. Rozenfel'd (1972) discriminates five types of image transformation: discretization, quantization, coding, approximation and filtration. As indicated by L. A. Bogomolov (1976), all these transformations can be used in automation of the process of interpretation of aerial and space photographs. However, automatic interpretation simplifies and to a definite degree distorts the information on the photograph. It is done independently of the environment and without reference to existing natural interrelationships. As indicated by discussion of these matters at international and national symposia, success in the automation of interpretation at this stage for the time being can be expected in the solution of special problems and in narrowly specialized fields of investigation.

The tasks of soil interpretation can be formulated in the following way: first, detection and outlining on aerospace photographs of territories with an identical structure of the soil cover, which must be defined as unit soil interpretation; second, determination of the content of the soil units detected on the photographs -- genetic soil interpretation; an important independent task is the extrapolation of the results obtained for individual points (profiles) or key sectors on the basis of visual-instrumental or instrumental (automated) interpretation of the soil cover.

The specific nature of the soil as a feature to be interpreted also determines the content of the process of analysis of the photomaterials (Vink, 1968, and others). It includes all aspects of their identification or photoreading and also the digital evaluation, determining the mutual relationship of the photoindicators detected in the interpretation. The analysis involves carrying out work for study of the individual components of the environment and their interrelationships to the soil cover. Yu. A. Liverovskiy (1962) mentions the need for using physiographic synthesis as a basis for soil interpretation. Its importance increases sharply in space investigations.

A specific property of use of space photographs in soil science is that in their interpretation (due to the great coverage of considerable territories) there is a marked increase in the role of indirect interpretation criteria, the geographic method for the study of space photographs and allowance for interrelationships and intercausalities of all environmental components.

In the study of soils from aerial and space photographs as a point of departure one must apply the principle expressed by V. V. Dokuchayev that the soil is part of the geographic landscape, is its "mirror." Soils and such factors of soil formation as relief and vegetation are reflected on photographs in a reduced generalized form. In this connection the interpretation of soils is essentially based on a comparative geographic analysis of the photoimage of natural or man-modified landscapes.

On the basis of the principles formulated by B. B. Polynov relative to elementary landscapes and types of terrain, the use of photographs makes it possible to determine interpretation criteria characterizing the soils of these landscapes. In formulating the principles for soil interpretation from photographs we used as a point of departure interpretation, on the one hand, of soils of natural landscapes, and on the other -- soils of cultivated (plowed) elementary landscapes.

The interpretation of soils and agricultural objects can be improved (especially in multizonal aerial and space surveys) if we know the characteristics of their reflectivity in a definite spectral zone and carry out a survey in those narrow ranges where the spectral differences between soils and planted crops are maximum. These matters will be considered below.

Spectral Reflectivity of Soils

Multizonal brightness of objects and features, including soils and agricultural crops, is a new and important interpretation criterion which makes it possible to carry out quantitative measurement of soils and agricultural fields on the basis of their image on photographs. With the use of scanning systems the digital processing of multispectral photographs can proceed until an image is obtained. For example, for studying the soils of the northeastern part of Kansas use was made of materials from a multispectral scanner having 15 spectral ranges in the zone 0.4-0.9 μm. The results of the scanning were registered directly on a magnetic tape which could be processed on an electronic computer. At the same time, a survey was made on 70-mm color and color IR film. In computer processing use was made of the differences in the spectral reflectivity of the soils (greatest in the near-IR spectral zone), which were registered by a scanner. In each of the sectors of the electromagnetic spectrum there are differences in the spectral brightness of the soils and therefore in working in each range use was made of the mean values of spectral reflectivity of soils (Carroll, 1973).

The use of the photoimage of one and the same objects, obtained simultaneously in different spectral zones, makes it possible to obtain additional information on soils and agricultural crops. It can be seen from a comparison of two aerial photographs of one of the experimental sectors in the steppe zone during spring in such a survey, taken in the red (640 nm) and orange-yellow (590 nm) spectral zones, that in the zone 640 nm there is reliable discrimination of typical chernozems from meadow-chernozem soils associated with depressions and also chernozems with different degrees of erosion. A field of winter rye stands out sharply amidst plowed areas of typical chernozems; in the zone 590 nm these differences are considerably weaker, but sectors of freshly plowed chernozems stand out better as a result of an increase in surface moisture content. In the field of winter rye it is easy to see a banding which is associated with the different nature of working of the soil, which is completely absent on photographs of the red spectral zone. Thus, a comparison of the photographs taken in different parts of the spectrum makes it possible to increase the interpretability of soils and agricultural fields.

In this connection, in our country and abroad great interest is being shown in study of the spectral characteristics of soils and agricultural crops surveyed in different zones of the electromagnetic spectrum. Investigations indicated differences in the spectral reflectivity of soils in dependence on their composition and state. It was established that there is an influence of the humus content, light-colored compounds (silicon and aluminum), carbonates, easily soluble salts, different iron compounds, and also moisture content and mechanical composition of the soils on the characteristics of spectral distribution of reflected radiations of soils. The curves of relative spectral reflectivity of soils (sands, clayey loams), determined under field conditions (Holmes, 1970), indicated that the maximum of the differences falls in the zone 0.6-0.7 μm. This is one of the survey zones adopted in working with the ERTS satellite.

An increase in soil moisture content to complete capillary moisture capacity reduces their reflectivity by a factor of 2-3 (Obukhov, Orlov, 1964). Yu. S. Tolchel'nikov (1959, 1974) notes that during summer under field conditions the soils dry out from the surface to an air-dry state. Accordingly, with a uniform mechanical composition the brightness of the soils has a direct relationship to its humus content.

N. P. Sorokina (1967) for typical chernozems studied the correlations between the coefficient of reflection for soils and their humus and carbonates content. It is shown that with a humus content of less than 5% there is a direct relationship between the quantity of humus and the logarithm of integral soil reflection.

The coefficient of spectral reflection of soils has been proposed; RC is determined using the formula

$$RC = 440 + 490 + 540 + 590 + 640 + 690/6$$

where 440, 490 and the others are the reflection values for wavelengths 440, 490 nm, etc.

In this section we will examine the spectral reflectivity of soils and its influence on their brightness in different spectral zones.

The coefficient of spectral reflection of soils is the ratio of the reflection value of the soil sample to the value for an ideal surface reflecting 100% of the light for all wavelengths. The term "reflection coefficient for soils" coincides with the term "brightness coefficient" (Krinov, 1947). For a definite wavelength λ it can be determined using the formula

$$r_\lambda = B_\lambda / B_0$$

where B_λ is the brightness of the soil surface and B_0 is the brightness of the standard (byrate plate) for identical illumination conditions.

Whereas in an analysis of the photoimage of soils on integral panchromatic photographs it is more important to take into account the reflection coefficient in the visible part of the spectrum, in a multizonal survey it is necessary to take into account the reflection (brightness) of soils at a definite wavelength.

The reflection coefficient for soils (with an accuracy to 0.1%) for a definite wavelength was determined directly from the spectral reflection curve, registered with a spectrophotometer. The SF-10 recording spectrophotometer makes it possible to obtain the absolute reflection value in the visible zone of the spectrum 400-750 nm. In the analysis use was made of air-dried samples passed through a 0.25-mm sieve. The samples were poured into instrument cells and leveled by a spherical glass in order to impart a uniform roughness to the sample surface during registry by the instrument.

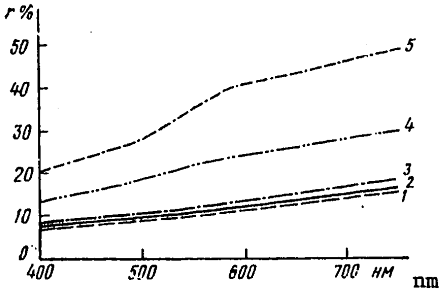

Fig. 2. Spectral reflection curves of experimental sector of steppe zone. 1) meadow-chernozem heavy clayey loam; 2) typical heavy clayey loam chernozem; 3) typical slightly eroded chernozem; 4) typical medium-eroded chernozem; 5) typical medium-eroded chernozem (depth 30-40 cm).

Soil samples of experimental sectors of the steppe and dry steppe zones were analyzed. Table 10 gives data on the spectral reflectivity of tilled soils of an experimental sector of the steppe zone. It can be seen that the total integral reflection coefficient for typical chernozems in the entire visible zone of the spectrum on the average is 10.7%. Some very insignificant increase in brightness was observed for typical chernozems with an increase (up to 11.8%) of effervescence.

Meadow-chernozem soils are close in reflectivity to chernozems (Fig. 2). In a dry state they cannot be distinguished in plowed land. The differences in meadow-chernozem soils against the background of chernozems are attributable to their different moisture content. They are reliably interpreted due to the nonidentical development of vegetation in these soils.

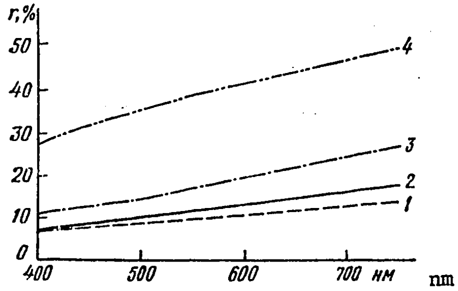

Fig. 3. Spectral reflection curves for soils of undulating sandy plain in experimental sector of dry steppe zone: 1) meadow-chestnut solonchak-like; 2) meadow-chestnut solonetz-like; 3) dark chestnut sandy loam; 4) meadow solonchak.

The reflectivity for slightly (12.6%) and especially for medium-eroded chernozems (19-22%) is sharply different from that of typical chernozems and meadow-chernozem soils. On photographs they are reliably interpreted from the light gray image tone.

In a multizonal survey of an experimental sector of the steppe zone use was made of photographs in the visible zone of the spectrum sensitive to the green (520 and 540 nm) and red (610-690 nm) zones. In the green and red spectral zones the reflection of typical chernozems and meadow-chernozem soils is almost identical. In the green zone these soils are more readily discriminated from calcareous excavated chernozems (the difference in the reflectivity of these soils in the green zone is 1.1-1.2%, in the red zone -- 0.6-0.7%). The differences in reflection between chernozems and their eroded varieties are sharply expressed in both the green and red spectral zones.

The spectral reflectivity of soils in the experimental sector in the dry steppe zone was analyzed for the three principal regions of this zone. Dark chestnut sandy loam, meadow-chestnut soils and solonchaks were studied in the territory of an undulating sandy plain. All these soils, especially solonchaks, are readily distinguished from one another on the basis of the mean reflection coefficient in the visible zone (Table 11). The spectral reflection curves for these soils are given in Fig. 3.

In an experimental sector of the dry steppe zone multizonal surveys were made at 520 and 540 nm, 610 and 690 nm. A comparative analysis of the reflectivity of soils in the green and red zones indicated the following. The greatest difference in the reflection values for dark chestnut and meadow-chestnut solonetz-like soils is observed in the red (610-690 nm) zone -- 5.4 and 6.1% respectively; in the green zone (520 and 540 nm) zone it is 2.7 and 3.1% respectively with a 4% difference in reflectivity of these soils in the entire visible spectral zone.

Salina and meadow solonchaks, having a salt crust on the surface, can be represented by an identical tone because the reflectivity of the salt crust (except for the blue-green zone) is close for them. However, solonchak vegetation is usually present at the surface of meadow solonchaks. Accordingly, on the photographs they differ reliably from salina solonchaks.

The difference between dark-chestnut and meadow-chestnut soils can be seen sharply, since for these RC = 12.5-14.9%; for meadow-steppe and steppe solonetz soils, however, RC = 23.3-24.3% (Table 12). The differences in the reflectivity of dark chestnut solonetz-like and meadow-chestnut soils are seen better in the red (610 and 720 nm) spectral zone -- 3.4 and 4% respectively, with a general average of 2.4%. In the blue-green zone the corresponding figure is 1.4-2.2%.

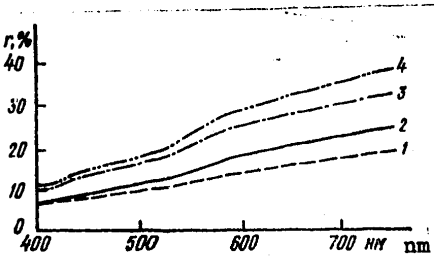

Fig. 4. Spectral reflection curves for soils of ancient runoff valley of experimental sector of dry-steppe zone: 1) meadow-chestnut solonetz-like; 2) dark chestnut solonetz-like; 3) meadow-steppe solonetz soils; 4) steppe solonetz soils.

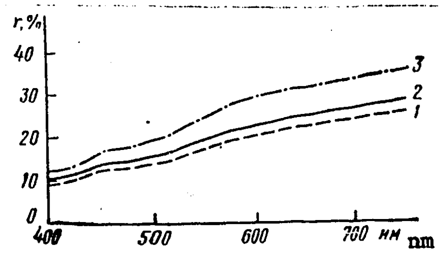

Fig. 5. Spectral reflection curves for soils of territory of plateau in experimental sector of dry steppe zone: 1) meadow-chestnut calcareous; 2) dark chestnut calcareous; 3) dark chestnut calcareous (small hillocks).

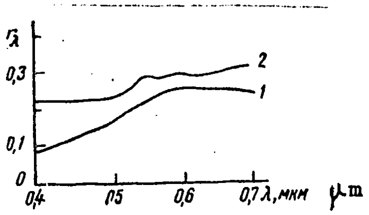

Fig. 6. Spectral image of territory of sandy desert (according to Kondrat'yev, et al., 1972): 1) ground measurements of surface; 2) measurement of surface from "Soyuz-9."

Steppe solonetz soils reflect more light and on photographs show up in a lighter tone than meadow-steppe solonetz soils (Fig. 4). These differences were also especially clearly established from space photographs of this territory during the spring survey period when a high soil field moisture content was expressed in a decrease in reflection of meadow-steppe solonetz soils.

The reflectivity of soils was also studied in the territory of plateaus with dark chestnut calcareous, meadow-chestnut calcareous and dark chestnut calcareous excavated soils of small hillocks. The reflectivity of these soils is shown in Fig. 5. The dark chestnut calcareous and meadow chestnut calcareous soils have a close general reflection coefficient -- 20.0 and 19.1% respectively (Table 13); it was somewhat higher in the red spectral zone — 24.4-27.6 and 22.8-26%; in the blue-green zone the differences in the reflection of these soils are equal to 0 or not more than 1%. In the dry steppe zone dark chestnut and meadow chestnut soils were most effectively interpreted from photographs taken in the red spectral zone.

Dark chestnut calcareous excavated soils -- small hillocks [at the mouth of marmot burrows] -- as a result of the considerable content of carbonates and the lesser humus content in the upper tilled horizon have a high reflectivity. On the photographs, in the green and especially in the red spectral zone, they were represented by a light gray, almost white tone.

As a result of study of the spectral reflectivity of soils in the steppe zone it became clear that the lesser the humus content in the soil, the greater is the reflectivity and the lighter is the soil image on the photographs. These indices are especially important in the interpretation of plowed sectors of the soil cover in the steppe zone.

Reflectivity measurements quite clearly indicated that the calcareousness of rock material is manifested sharply in the blue-green spectral zone, close to the ultraviolet, where very low reflection coefficients are noted for the soils.

At the same time, study of the spectral reflectivity of soils revealed the necessity for taking into account not only the general reflection coefficient, but also the peculiarities of reflection in a specific spectral zone. Their investigation makes possible a still greater increase in the effectiveness of soil cover interpretation. The spectral peculiarities of the soils and agricultural crops, manifested in different tonality on multizonal photographs, constitute an important interpretation criterion.

Spectrometric survey of soil cover. Work is successfully developing on study of the spectral brightness of the earth's surface synchronously under ground conditions, from aircraft and from space.

[redacted]

As a result of investigation of spectral reflectivity of soils and vegetation (Kondrat'yev, et al., 1972) in the territory of a sandy desert and from space from the "Soyuz-9" from an altitude of 250 km (synchronously) it was possible to define two fundamental principles: 1) during a survey from space there is an increase in the total brightness of the soil-vegetation associations in comparison with surface measurements; 2) particularly sharp differences in their reflectivity are observed in the blue-green region of the electromagnetic spectrum (Fig. 6).

A spectrometric survey of the earth's surface does not give images in the form of photographs. It serves for obtaining the spectral characteristics of soils and areas of agricultural crops and the choice of the optimum survey zones in a multizonal survey (Rachkulik, Sitnikova, 1976; Tolchel'nikov, Chukov, 1977). For example, ground investigations carried out for study of the surface moisture content of typical chernozems in an experimental sector of the steppe zone using a spectrometer operating in the spectral range 0.4-0.5μm indicated that the soil dries out rapidly from the surface and moisture content exerts little influence on the spectral brightness coefficients of the soil (Bulatov, et al., 1976).

In comparison with a photographic survey, a spectrometric survey for each soil or agricultural crop, in dependence on the selected spectral range and spectral resolution of the apparatus, can give a large number of characteristics. According to data published by Vinogradov and Kondrat'yev (1971), it appears that in the range $\lambda\lambda$0.4-0.7μm with a spectral resolution $\Delta\lambda$ 0.5μm in one spectrum it is possible to obtain up to 60 characteristics of one soil. An important index is the ratio of the spectral brightness coefficients (K_λ) for definite spectral intervals. It is assumed that

$$K_\lambda = r\lambda_{red}\ 0.64 - 0.66/r\lambda_{IR}\ 0.81\text{-}0.85\ \mu\text{m}$$

is of interest for evaluating moisture content and the humus content in the soil (Vinogradov, 1976).

A spectrometric survey is of great importance for the sensing of agricultural crops. A study made by foreign specialists in one such experiment using about 40,000 spectra of these crops indicated that for the recognition of plantings of soy beans, corn, oats, wheat and red clover it is most effective to study their spectral brightnesses in three ranges: 0.40-0.44, 0.66-0.72, 0.72-0.80μm. The percentage of correct identification of these crops is 85-92%.

We note in conclusion that spectrometric sensing of soils and sown crops, based on registry of the reflection spectra of sunlight and the characteristic emission of the earth's surface, with respect to the peculiarities of the measurement method, can be subdivided into: 1) visible and near-IR -- 0.3-1.1μm; IR, or thermal -- 3.0-300μm; 3) microwave (millimeter, centimeter and decimeter radiations).

At the present time these methods for studying soils and agricultural crops are in the stage of experimental development in our country.

Interpretation of Soil Criteria

The specific nature of interpretation of the soil cover relates, in particular, to the principal criteria (direct and indirect) used in the interpretation of aerial and space photographs. The direct interpretation criteria for the soil cover are tone, color, pattern (texture of the photoimage), size and shape of the soil units; the indirect criteria are nature of relief and hydrography, vegetation, man's agricultural activity.

In soil interpretation it is infeasible to be guided by any one interpretation criterion, such as phototone. The most correct analysis of the photoimage of the soil cover can be made only when all the interpretation criteria are taken into account.

Tone of Photoimage; its Visual and Quantitative Evaluation

The tone of a photoimage of soil and agricultural features on aerial and space photographs is one of the important, but rather variable criteria. Visually in soil interpretation it is possible to make successful use of a gray scale of tones having the following seven stages (Mikhaylov, 1959).

Tone	Density
1. White	0.1 or less
2. Almost white	0.2-0.3
3. Light gray	0.4-0.6
4. Gray	0.7-1.1
5. Dark gray	1.2-1.6
6. Almost black	1.7-2.1
7. Black	2.2 or more

Visually it is possible to discriminate nine tones: 1) white; 2) almost white; 3) light; 4) light gray; 5) gray; 6) dark gray; 7) dark; 8) almost black; 9) black

In soil interpretation the presence of a tonal difference between adjacent soil units is exceptionally important. The interpretation of the soil cover will be difficult or impossible if its image tone merges with the general background of the terrain and therefore the transmission of the boundary optical image contrast (difference in image tone) is the primary criterion of interpretability of soil formations. In actuality, if the surface brightness of one soil unit does not differ from the surface brightness of another, the boundary between them will not be visible on an aerial or space photograph.

The brightness contrast is characterized by the contrast value:

$$K_{br} = B_1 - B/B,$$

where B_1 is the brightness of the object; B is the brightness of the background surrounding the object. The minimum brightness difference which is discriminated by the eye and which is detected by the photoemulsion is the contrast threshold and this is denoted $\Delta B/B$ (ΔB is the minimum brightness difference between the object and the background perceived by the eye). The brightness contrast threshold for the human eye is ~2%. If the contrast between a soil unit and the surrounding background is above the threshold of contrast sensitivity, it is reflected by the photographic emulsion.

In addition to a visual evaluation of the tonality of different soils and sown crops, it is possible to carry out quantitative measurements. Microphotometers of the MF-4, IFO-451 and other types are used in measuring the different density of aerial photographs.

Using a new electronic instrument, the "Kvantimet-720" image analyzer, it is possible to discriminate 64 levels of gray tone from photographs and from films. On the basis of numerous visual-instrumental determinations these 64 detection levels, in dependence on the determination of the gray tone on aerospace photographs, were classified into 11 steps in the following way:

1. Black	0–10	7. Gray	35–40
2. Almost black	10–15	8. Light gray	40–45
3. Gray-black	15–20	9. Light	45–50
4. Dark	20–25	10. Almost white	50–55
5. Dark gray	25–30	11. White	55–64
6. Darkish-gray	30–35		

On the basis of investigations for measuring the difference $\Delta B = B_1 - B_2$ of the boundary optical image contrast of different soil units and plantings of agricultural crops it was possible to prepare a scale of the degree of interpretability of the objects (in relative units).

[The above quantitative scale for the discrimination of gray tones was prepared in determining the detection level from black to white (0–64) with a setting of sensitivity (response) in manual and automatic regimes equal to 5.]

Degree of interpretability of objects	Difference in boundary contrast (levels of gray tone)
Not interpreted or determined doubtedfully	0–2
Weak	3–5
Medium	6–10
Good	11–20
Sharp	21–30 or more

Table 10

Spectral Reflectivity of Plowed Soils in Experimental Sector of Steppe Zone

Soils	№ 1 разреза	Глубина, см 2	Цвет почвы 3	Гумус 4	CaCO₃	5 Величина отражения света (в %) при различных длинах волн, нм										6 Коэффициент отражения (КО), %
				%		440	490	520	540	580	590	610	640	690	720	
Typical and slightly leached heavy clayey loam chernozems	1	0–25	Темно-серый 7	6.28	No	8	9	10	10.5	11.5	11.5	12	12.5	14	15	10.8
		30–40		5.11		9	10	10.5	11	12	12	13	13.5	15	16	
	2	0–20	То же 8	5.99	»	8	8.5	9.5	10	10.5	10.5	11.5	12.5	14	15	10.5
		30–40		4.91		8.5	9.0	10	10.5	12	12	12.5	13.5	15	16	
	9	0–25	» »	6.36	»	7.5	8	9.5	10	11	11	11.5	12	13.5	14	10.3
		30–40		5.32		9	10	11	11.5	13	13.5	14.5	15	17.5	18	
	11	0–25	» »	6.31	»	7	7.5	8.5	9.5	10.5	11	11	11.5	13	13.5	9.8
		35–45		5.33		7.5	8	9.5	10	11	11	11.5	12.5	14	15	
	12	0–25	» »	5.69	»	8	8.5	9.5	10	10.5	11	11	11	13.5	14.5	10.3
		35–45		4.03		8	8.5	9.5	10	11	11	11.5	11.5	14.5	15.5	
	Mean	0–20		6.13	»	7.8	8.3	9.4	10	10.8	11	11.4	11.9	13.6	14.4	10.4
Heavy clayey loam typical chernozems with increased effervescence (excavated)	5	0–20	» »	6.93	0.58	8.5	9.5	10	10.5	11.5	12	12	12.5	14.5	15	11.1
		30–40		5.69	5.42	11	11.5	12.5	13	14.5	15	15.5	16	18	19	
	13	0–20	» »	5.69	0.08	9	9.5	10.5	11.5	12	12	13	13.5	15.5	16.5	11.8
		35–45		4.08	0.58	9	10	11	12	13	13	14	15	17	18.5	
	14	0–25	» »	6.20	0.04	7	8.5	9.5	10	11	11	11.6	11.5	14	15	10.3
		30–40		4.50	1.21	8	8.5	9.5	10	11	11	11.5	11.5	14	15	
	Mean	0–20		6.27	0.23	8.9	9.2	10	10.5	11.5	11.8	12.0	12.5	14.5	15.5	11.1
Typical eroded chernozems:																
slightly	3	0–20	Буро-серый 9	5.48	5.79	9.5	10.5	11	12	13	13.5	14	14.5	16	17.5	12.6
		35–45		3.88	6.58	11.5	13.5	14.5	15.5	17.5	18	18.5	19.5	21	22.5	
medium	4	0–25	Серо-бурый 10	3.88	19.09	14.5	16.5	18	19.5	21	21.5	22	22.5	25	26	19.8
		35–45		1.03	19.31	21.5	25.5	30	32.5	38	39	40.5	42	44.5	46	
medium	7	0–25	То же	2.95	12.39	15.5	18	20	21	23.5	24	25	26	28	29	22.0
		30–40		0.83	12.48	23.5	27.5	31.5	34	40	41	42	43.5	46	47.5	
Heavy clayey loam meadow-chernozem leached soils (swales)	35	0–20	Темно-серый	7.45	No	7.5	8.5	9	9.5	11	11	11.5	12	13.5	14.5	10.3
	36	0–20	То же	7.14	»	7.5	8.5	9	9.5	11	11	11.5	12.5	14	15	10.5
	37	0–20	»	7.56	»	7	8	8.5	9	10	10.5	11	12	13.5	14.5	10.3
	38	0–20	»	7.24		7.5	8.5	9	9.5	10.5	11	11.5	12.5	14	15	10.5
	39	0–20	»	7.77		7	8	8.5	9	11	10.5	11	11	13	14.5	9.8
	Mean	0–20		7.43		7.3	8.3	8.8	9.3	10.5	10.8	11.3	12.1	13.6	11.7	10.2

KEY:

1. No of test pit
2. Depth, cm
3. Soil color
4. Humus
5. Light reflection (in %) with different wavelengths, nm
6. Reflection coefficient (RC), %

7) Dark gray
8) Same
9) Brown gray
10) Gray brown

Table 11

Spectral Reflectivity of Soils of Undulating Sandy Plain of Experimental Sector of Dry Steppe Zone

Soils	No of test pit	Глубина, см 1	Цвет почвы 2	3 Гумус	CaCO3	4 Величина отражения света (в %) при различных длинах волн, нм										Reflection coefficient
				%		440	490	520	540	580	590	610	640	690	720	
Dark chestnut sandy loam	33	0—10	Буро-серый 5	1,00	Нет 9	12,5	14	15,5	16,5	19	19,5	20,5	21,5	24	25,5	18
		25—35		0,65		12,5	14	16	18	22	23,5	24,5	26	30	32,5	
	441	0—15	То же 6	1,48	»	10,5	13	14,5	15,5	17,5	18	19	20	22	23	16,5
		30—40		0,81		10,5	13	15	16,5	21	22	23,5	25,5	28,5	30,5	
	40	0—15	» »	1,34		9,5	12	13,5	15	17,5	18,5	19,5	20,5	22,5	24	16,1
		26—36		0,88		10	12	14	16	21,5	22,5	24,5	26,5	30,5	30,5	32,5
	42	0—15	» »	1,65	»	9	10,5	12	13	16	16,5	17,5	18,5	20,5	22	14,6
		30—40		0,82		11	13,5	16	18	23,5	24,5	26,5	28,5	33	35,5	
	401	0—15	» »	1,39	»	8,5	10	12	13,5	16,5	17,5	18,5	19,5	22,5	24	15,1
	410	0—15	» »	1,61	»	10	12	13,5	14,5	17	18	19	20	21,5	23	15,8
	Mean	0—15		1,41		10	11,8	13,5	14,5	17,1	18	19	20	22,1	23,5	16,2
Meadow-chestnut solonetz-like light clayey loam	43	0—20	Темно-серый 7	2.98	Нет	8.5	9.5	10.5	11.5	13	13.5	14	15	16.5	18	12.3
		30—40		1,29		11	13	14,5	16	19	19,5	20,5	21,5	24,5	26	
	45	0—20	То же 6	3.50	»	8,5	9,5	10,5	11,5	12	12,5	13,5	14,5	16,5	17,5	12,1
		25—35		1,49		10,5	12,5	14	15	18	18,5	19,5	20,5	23	24,5	
	408	0—20	» »	2,30	»	6,5	8	8,5	9,5	11	11	12	12,5	14,5	15,5	10,3
		30—40		1,56												
	35	0—10	» »	3,31	»	12	13,5	14	14,5	16	16,5	17	18	20	21,5	15,6
		30—40		1,50		15	16,5	17,5	19	21	21,5	22,5	24	27	28,5	
	442	0—15	» »	2,72	»	8	9	9,5	10	11	11	11,5	12	13	14	10,5
		30—40		0,81		11	12,5	14	15	17,5	18	19	20	22	24	
	Mean	0—15		2,96		8,6	9,8	10,6	11,4	12,6	12,8	13,6	14,4	16,0	17,2	12,2
Meadow-chestnut solonchak-like, light clayey loam	37	0—10	Темно-серый 7	3,19	Нет	7,5	8,5	9	9,5	10,5	10,5	11	11,5	13	14	10,0
		30—40		0.72		10	11,5	12,5	13,5	15	15,5	16,5	17,5	19,5	20,5	
	443	0—10	То же 6	3,21	Нет	9,5	10	11	11,5	12	12,5	13	13,5	15	15,5	12,0
		20—30		2,29	0,2	9,5	10	11	11,5	12	12,5	13	13,5	15	15,6	
Meadow clayey solonchak	36	0—0.5	Почти белый 8		4.58	31	34,5	36,5	38,5	41	41,5	42,5	44	47	48,5	39,3
		0—10		0,41	3.40	26	31	34	36	39,5	40	41,5	42,5	45	46	
Weedy clayey solonchak	439	0—0,5	То же 6	—	0,57	33	37	39	40,5	43	43,5	44	45	47	48,5	40,8
		0—5		—	0,89	25	28,5	30,5	32	34	34,5	35,5	36,5	38,5	40,5	
		10—15		—	3,40	19,5	23,5	26	28	31,5	32	33,5	34,5	36,5	38	

KEY:

1) Depth, cm
2) Soil color
3) Humus
4) Light reflection (in %) for different wavelengths, nm
5) Brown-gray
6) Same
7) Dark gray
8) Almost white
9) No

Table 12

Spectral Reflectivity of Soils of Slightly Undulating Plain of Ancient Runoff Valley of Experimental Sector of Dry Steppe Zone

Soils	No of test pit	Глубина, см 1	Цвет почвы 2	Гумус 3	CaCO₃	Величина отражения света (в %) при различных длинах волн, нм 4										Reflection coefficient
				%		440	490	520	540	580	590	610	640	690	720	
Dark chestnut solonetz-like clayey loam	49	0—20	Буровато-серый 5	3,21	0,20	10	12,5	14	15	18	18,5	19	20	22	23	16,3
		30—40		2,28	3,00	13,5	16,5	18,5	20	23,5	24	25	26	28	29	
	51	0—20	Same	3,26	0,41	10	11,5	13,5	14,5	16,5	17,5	18	19	21	22,5	15,5
		35—45		1,71	1,79	11	14	16,5	18,5	23,5	24	25,5	27	30	32	
	425	0—15	» »	2,20	No	7,5	9,5	11	12	14,5	15	16	16,5	19	20	13,2
	428	0—15	» »	1,91	»	8,5	10,5	12,5	13,5	17	17,5	18	19,5	22	23	15,0
		30—40		1,53		8,5	10,5	12,5	14	18,5	19,5	21	22,5	25	27	
	434	0—15	» »	2,77	»	9	11	12	13,5	16	16,5	17	18,5	20,5	21,5	14,6
		25—35		1,29		12,5	14,5	16,5	18	21,5	22,5	24	25	27,5	29	
	Mean	0—15		2,67		8,8	11,0	13,0	13,6	16,4	17	17,6	18,6	20,8	22,0	14,9
Solonetz-like clayey loam meadow-chestnut soils	57	0—20	Темно-серый 6	3,53	No	9,5	11	12,5	13,5	15,5	16	17	17,5	20	21	14,5
		35—45		1,06		12,5	16	19	22	29	30	32	33,5	37	39,5	
	422	0—15	Same	3,07	»	8,0	9,5	10,5	11	12,5	13	13,5	14,5	16	17	12,0
		25—35				8,5	9,9	11	11,5	13	13,5	14	15	16,5	17,5	
	427	0—15	» »	2,34	»	8	9,5	10,5	11,5	13,5	14	15	16	17,5	18,5	12,6
		30—40		1,63		8	10	11	12	14,5	15	16	17	19	20,5	
	429	0—15	» »	3,49	»	8	9,5	10,5	11,5	13	13,5	14	15	17	18	12,3
		30—40		1,86		8,5	10,5	12	13,5	16	16,5	17,5	18,5	21	22,5	
	433	0—15	» »	4,69	»	7,5	9	10	10,5	12	12	12,5	13,5	15	16	11,2
		30—40		2,25		10	12	13	14	16,5	17	18	19	21	22,5	
	Mean	0—15		3,42		8,2	9,6	10,8	11,4	13,2	13,6	14,2	15,2	17	18	12,5

Continuation of Table 12

Soils	No of test pit	Глубина, см 1	Цвет почвы 2	Гумус 3	CaCO$_3$	4 Величина отражения света (в %) при различных длинах волн, нм										Reflection coefficient
				%		440	490	520	540	580	590	610	640	690	720	
Fine clayey loam meadow-steppe solonetz soils	50	0—20	Серо-бурый 7	2,12	No	12,5	16	18,5	20	25	26	27,5	28,5	31,5	33	22,3
		25—35		1,60	0,41	11,5	14,5	17	19,5	25	26	28	29	32,5	34,5	
	51a	0—20	То же 8	2,33	2,41	12	15	17,5	19,5	24,5	25	27	28,5	31,5	33,5	21,8
		30—40		0,98	0,20	17	20,5	24	26,5	33	34	35	36,5	39	41	
	421	0—15	» »	2,08	No	12,5	15,5	18	19,5	23,5	24	25	27	29,5	31	21,3
		23—28		1,93		11,5	14,5	17	19	23,5	24	25	27	30	31,5	
	423	0—15	» »	1,59	»	11	14	16	18	22	23	24	25,5	28,5	30	20,3
		20—30		1,16		10	13	15	17	22,5	23,5	25,5	26,5	29,5	31	
	430	0—15	» »	1,86	»	11,5	14,5	17	18,5	23	24	25,5	27	30	31,5	20,8
	Mean	0—15		2,00		11,8	12,2	17,2	19	23,6	24,4	25,8	27,2	30,2	31,8	21,3
Fine and medium clayey loam and clayey solonetz soils	58	0—20	Бурый 9	1,92	0,41	13	16,5	19	22	27	28	30	31	34,5	36	24,2
		30—40		0,51	3,20	42,5	49,5	54,5	57,5	62,5	63,5	64,5	65,5	67,5	68,5	
	59	0—20	»	1,70	No	15	18	21,5	24	29	29,5	31	33	36,5	38,5	26,2
		30—40		0,54	1,19	41,5	48	52,5	55	59,5	60	61	62,5	65,5	67	
	431	0—18	»	1,53	No	14	17,5	20	22	26	27	29	30	33	35	24,0
		18—28		0,76		11	14	17	19,5	25	26	27,5	29,5	33,5	35,5	
	438	0—15	»	2,06	»	13,5	16,5	18,5	20,5	24,5	25	27,5	28	30,5	32	22,7
		30—40		—		11	14	17	19,5	26	27	29	31	35	37	
	Mean	0—20		1,75		14	17,5	20	22,3	26,8	27,5	29,3	30,5	34	35,5	24,3

KEY:

1) Depth, cm	4) Light reflection (in %) for different wavelengths, nm	6) Dark gray
2) Soil color	5) Brownish-gray	7) Gray-brown
3) Humus		8) Same
		9) Brown

Table 13

Spectral Reflectivity of Soils of Territory of Plateaus of Experimental Sector in Dry Steppe

Soils	№ разреза 1	Depth cm	Soil color	Гумус 2	CaCO₃	3 Величина отражения света (в %) при различных длинах волн, нм										Reflection coefficient
				%		440	490	520	540	580	590	610	640	690	720	
Calcareous clayey dark chestnut soils	411	0—15	Серый	3,37	3,40	13	15,5	17,5	19	22	22,5	23,5	24,5	26,5	27,5	20,1
		30—40		2,78	5,38	13	15,5	18	19,5	22,5	23	24,5	25,5	27,5	28,5	
	412	0—15	» 4	3,32	4,40	12,5	15	17,5	19	22,5	23	24	24,5	27	28	20,2
		30—40		2,49	6,33	14	17	19,5	21	24	25	26	27	29,5	31	
	416	0—15	»	3,67	4,41	13,5	15,5	18	19,5	22,5	23	24	25	27	28	20,5
		30—40		2,27	7,40	13,5	15,5	18,5	20	23,5	24,5	25	26	28,5	29,5	
	420	0—15	»	3,19	3,98	13	15,5	17,5	19	22	22,5	23,5	24,5	26,5	27,5	20,1
		30—40		2,37	6,78	14	16,5	19	20	20,5	24	24	25	29	30,5	
	446	0—15	»	3,44	3,50	12	15	16,5	18	21	21,5	22,5	23,5	25	27	19,2
		30—40		2,34	7,69	13,5	16,5	19	20,5	24	25	26	27	29	30,5	
	Mean	0—15		3,40	3,31	12,8	15,4	17,4	19,0	22,0	22,4	23,4	24,4	26,2	27,6	20,0
Calcareous excavated (marmot holes) heavy clayey loam dark chestnut soils	414	0—15	5 Светло-бурый	2,64	7,38	13,5	15,5	19,5	21,5	25,5	26,5	27,5	29,5	30,5	32	22,6
		30—40		2,30	11,58	16,5	20,5	23,5	26	31	31,5	33	35	37,5	38,5	
	415	0—15	Same	2,71	6,90	14,5	18	20,5	22,5	26,5	27,5	29	30	32	33	24,0
		30—40		2,13	8,99	14,5	18	20,5	22,5	26,5	27,5	29	30	32	33	
	417	0—15	» »	2,66	6,91	18	20	22,5	23,5	28	28,5	29,5	32,5	33	34,5	25,5
	419	0—15	» »	2,80	6,90	15	19	21,5	23,5	27,5	28,5	29,5	30,5	33	34,5	24,8
		30—40		2,46	9,28	16,5	20,5	23,5	25,5	30,5	31	32,5	33,5	36	37,5	
	447	0—15	» »	2,58	5,68	15	18,5	21,5	23,5	28	29	30	31	33,5	35	24,8
		30—40		2,15	13,49	17,5	21,5	25,5	28	34	35	36,5	37,5	40,5	42,5	
	Mean	0—15		2,68	7,38	15,0	18,0	21,5	23,5	27,0	28,0	29,3	30,3	32,4	34,5	24,4
Calcareous clayey meadow-chestnut soils	413	0—15	6 Темно-серый	3,91	1,02	14,5	17	18	19,5	21,5	22	22,5	23	25	26	20,1
		30—40		2,69	1,20	16	19	20,5	22	24	24	25,5	26,5	29	30	
	416	0—15	Same	3,67	4,41	13,5	15,5	18	19,5	22,5	23	24	25	27	28	20,5
		30—40		2,27	7,40	13,5	15,5	18,5	20	23,5	24,5	25	26	28,5	29,5	
	444	0—15	» »	3,63	4,40	11,5	13,5	15,5	16,5	19,5	20	21	22	24	25	17,8
		30—40		2,77	6,00	14,5	17,5	19,5	21	24,5	25	26	27,5	29,5	31	
	445	0—15	» »	3,54	4,40	11,5	13,5	15,5	16,5	19,5	20	21	21,5	23,5	24,5	18,3
		30—40		2,63	6,90	14,5	17,5	19,5	21	24	24,5	26	27	28	29,5	
	448	0—15	» »	3,49	3,90	13	15,5	17,5	18,5	21	21,5	22	23	24,5	26,5	19,0
		30—40		2,63	5,70											
	Mean	0—15		3,65	3,75	12,8	15,0	16,8	18,0	20,8	21,2	22	22,8	24,8	26,0	19,1

KEY:
1. No of test pit
2. Humus
3. Light reflection (in %) for different wavelengths, nm
4. Gray
5) Light brown
6) Dark gray

Table 14

Content of Humus, Phosphorus and Potassium in Soils With Different Levels of Fertility in One of Fields of Experimental Sector of Steppe Zone. Soils -- Typical, Leached and Calcareous (Excavated) Chernozems

	Гумус по Тюрину, % 1		Фосфор по Чирикову 2		Калий по Масловой 3	
			мг на 100 г почвы 4			
	0—20	30—40	0—20	30—40	0—20	30—40
			Level I			
	6,35	5,55	10,4	8,6	20	18
	6,66	6,20	10,4	8,0	20	16
	6,71	5,98	12,1	8,6	18	15
	6,09	5,67	12,0	9,2	18	16
	6,79	6,61	11,2	6,3	16	15
	6,50	6,35	9,5	7,7	17	15
	6,22	5,61	8,2	6,8	17	15
Mean	6,48	6,00	10,5	7,7	18	16
			Level II			
	6,60	5,96	8,0	—	17	15
	6,71	6,07	9,9	7,2	15	15
	6,79	5,87	7,6	5,0	17	15
	6,60	6,18	6,9	5,9	20	16
	6,79	6,72	—	6,1	18	17
	6,44	6,20	6,1	6,1	17	16
	6,20	5,74	8,2	7,8	16	15
	6,50	6,35	8,1	7,6	20	15
	6,66	5,69	9,0	8,0	15	14
	6,18	5,43	6,8	6,1	14	14
	5,26	5,08	6,6	6,1	15	15
	6,18	5,43	8,0	8,2	15	14
	6,16	5,94	8,2	6,1	17	17
	6,60	6,02	9,2	8,2	15	14
	6,73	6,42	8,2	8,2	15	14
	6,86	5,98	10,2	7,6	15	15
	6,24	5,89	8,2	7,8	16	15
	5,89	5,58	8,2	—	15	15
	6,60	6,42	9,0	8,6	18	16
	5,71	5,58	7,5	6,1	17	14
	6,60	5,70	8,2	7,7	17	16
Mean	6,40	5,87	8,5	7,0	16	15
			Level III			
	6,75	6,29	5,9	—	15	13
	6,35	5,10	5,7	3,8	13	12
	6,11	5,23	6,1	5,2	15	12
	6,11	5,63	6,6	6,6	13	13
	6,42	6,29	7,4	7,6	15	14
	6,38	5,54	6,4	3,2	15	13
	6,68	6,42	6,5	6,2	14	13
	6,44	6,38	7,5	6,5	17	17
Mean	6,38	5,86	6,5	5,6	14	13

KEY:

1. Humus (%), according to Tyurin
2. Phosphorus, according to Chirikov
3. Potassium, according to Maslova
4. mg per 100 g of soil

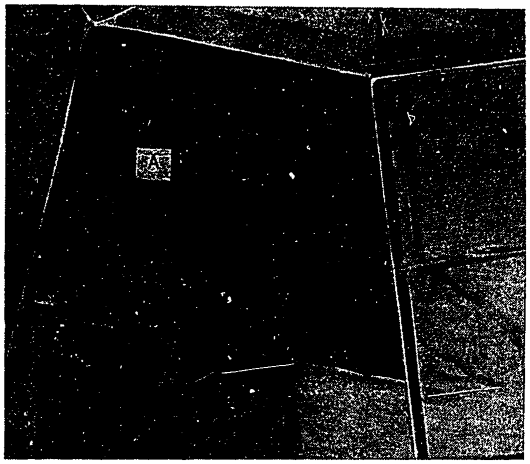

Fig. 7. Aerial photograph of territory of experimental sector of steppe zone obtained in red spectral zone (enlargement 3^x); A) field of winter rye.

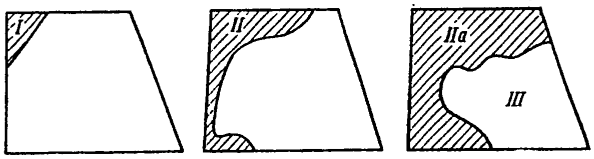

Fig. 8. Levels of gray tone (I, II, IIa, III) detected on aerial photograph using "Kvantimet-720" instrument. Field of winter rye. Soil -- typical chernozem and highly leached chernozem; survey time -- spring of 1973; isopanchromatic film; detection levels from white to black tones.

Thereafter the data from this scale were used in evaluating the reliability of interpretation of the soil cover and agricultural fields on both integral and on multizonal aerial and space photographs and films.

It was established in the course of our investigations that the discretization of the initial continuous half-tone image of the soil-vegetation cover on the photographs into a number of intervals with their quantitative discrete coding facilitates the discrimination of regions of the photograph with similar half-tone intervals. This ensures a better visual interpretation of slight changes in the brightnesses of the analyzed photograph and increases the sharpness of perception of vaguely expressed boundaries of soil-vegetation units. The processing of images on the "Kvantimet-720" requires the active participation of the interpreter,

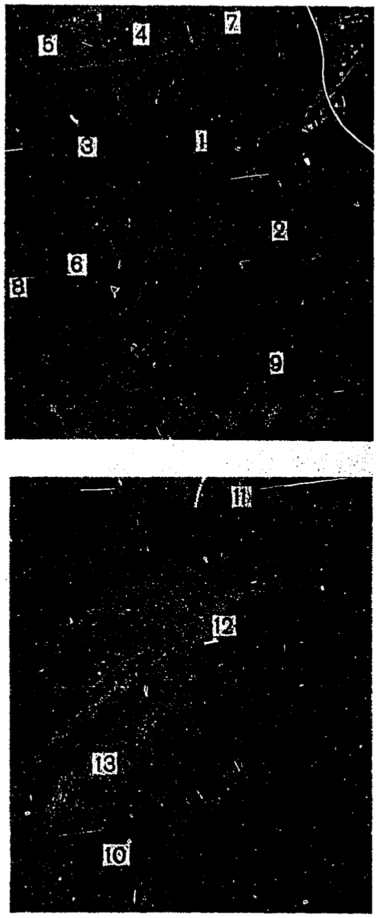

Fig. 9. Color spectrozonal aerial photographs of territory of experimental sector in the steppe zone. Survey time -- spring. Water divide sector (at top). Soils -- typical and leached chernozems with participation of excavated soils (at mouth of marmot burrows) on water divides and slightly and moderately eroded soils on slopes: 1) fallow; 2) field with boron freshly applied; 3) winter rye; 4) vetch-oats (sown on 12 April); 5) peas (sown on 10 April); 6) barley (sown on 9-10 April); 7) gardens; 8) perennial grasses (regrassing of slopes); 9) meadow-steppe vegetation (meadow-chernozem soils). Floodplain sector (at bottom): 10) winter rye, in spring grazed by cattle; 11) stubble (prior year with weeds); 12) alluvial-meadow; 13) alluvial-meadow-swampy soils.

who together with the machine ensures the most complete and precise solution of the formulated problems in the soil interpretation of the image of aerial and space photographs and soil mapping.

The "Kvantimet-720" instrument makes it possible, amidst seemingly visually uniform, almost white, gray or almost black images of agricultural fields or soil units, to detect a differentiation in tone on the photographs. This is of great importance for soil mapping. A study of tone differentiation is of considerable interest because it is related to differences of soils, their fertility and yields, the state and development of agricultural crops.

As a result of quantization by use of the "Kvantimet-720" for an almost uniform white image of a sugar beet field (soil -- typical chernozem) it was possible to discriminate three units different with respect to the level of gray tone, reflecting the state of development and maturity of sugar beets. The almost black tone around the sugar beet field on the photograph corresponds to the photoimage of a plowed surface of typical chernozem.

Figures 7 and 8 show the discrimination of gray tone levels for a visually uniform, almost black photoimage of a field of winter rye (A). There is some difference in discrimination of the units from the photograph and from the film, but on the whole the general image pattern is retained. The first level of the darkest image tone for winter rye was discovered at the intersection of two roads in the direction of a populated place. The second is situated along roads emanating from the populated place. It can be assumed that these sectors are the best cultivated and fertilized. In the course of the investigations these assumptions were confirmed. Table 14 gives data on content of humus and mobile phosphorus and potassium. With respect to soil humus supplies, the three considered levels are identical, whereas with respect to content of phosphorus and potassium there are differences.

In the autumn of 1975, at the three levels of the investigated field discriminated by means of an image analyzer, a determination was made of the yield of clover (aftercrop). The data cited in Table 15 indicate a difference in the three levels with respect to crop yield.

Thus, the tonal differences on the photographs (frequently not distinguishable visually) by means of modern electronic readout instruments can be used for discriminating soils with respect to the degree of soil cultivation and in determining the yield of agricultural crops.

Table 16 gives the changes in tone of the photoimage of the principal soils in the steppe zone (for a dry surface) in their interpretation from isopanchromatic photographs.

Characteristics of the photoimage tone of soils on space photographs. On space photographs another important criterion for interpretation of the soil cover is tone. In the steppe zone gray and light gray tones correspond to chestnut soils; a dark gray tone is characteristic for typical and ordinary chernozems. A bright-light tone corresponds to solonchaks.

On the basis of photoimage tone (dark gray, almost black) alluvial-moist-meadow soils of a low floodplain there is a reliable discrimination from alluvial-meadow steppized soils of a high floodplain. A change in image tone on space photographs serves as an important indicator of the nature of moistening of the soil cover. For example, on a space photograph of the territory of Texas obtained from "Gemini-4" on the basis of the dark tone of the photoimage it is possible to determine the zone of soil cover moistening as a result of a recent rain over an enormous territory. The area of the moistened soils has an elongated conical shape.

A specific problem in the use of space materials in soil science is that on space photographs we must frequently deal with the integral phototone of the image of soil and agricultural features. A study of individual tonal components of individual features and a study of their leading role in the generalizing photoimage of a space photograph is one of the most important scientific tasks of the immediate future.

During recent years extensive use has been made of a multizonal aerial and space survey of natural features. In the interpretation of the soil cover on photographs taken synchronously for the same territorial sector, but in different zones of the electromagnetic spectrum, the principal interpretation criterion is a change in tone and the degree of image contrast for different soils.

One and the same soil and agricultural units on photographs in different spectral zones show up in a different tone. For example, in the territory of an experimental sector of the steppe zone a change in the phototone of fields occupied by sugar beets or perennial grasses in different spectral zones varies from almost white to dark gray. However, the photoimage of fields occupied by winter crops changes to a lesser degree and the image tone of plowed sectors of typical chernozems remains virtually constant on photographs in different spectral zones. These characteristics of a multizone survey make it possible to carry out a more objective interpretation of the soil cover and the use of photometric instruments makes possible an approach to obtaining the quantitative characteristics and automation of the interpretation process.

Color of Photoimage of Soil Cover on "Natural" and Spectrozonal Photographs

In connection with the development of color and especially spectrozonal surveys of the soil cover an important direct interpretation criterion is the color of the photoimage of soils, vegetation and agricultural crops. L. M. Gol'dman (1960), Yu. A. Zaytsev, L. A. Mukhina (1966), Polyakov (1972), Simakova (1959), Shvede (1977), J. T. Parry, et al. (1969) note that on photographs with natural or conventional color transmission the color is more constant than the phototone of black-and-white photographs. Changes in survey conditions and differences in character of the surface cause only insignificant changes in the brightness of the color and saturation, but not the color of the image, which makes it possible to use color as a stable interpretation criterion for soils and agricultural crops.

Color three-layer aerial and space photographs give a terrain image in colors close to natural. For example, sectors of the soil cover subjected to plowing and covered by an agricultural crop differ from one another in color. In contrast to areas of chernozems having a brownish-dark gray image color, areas of meadow or alluvial soils show up in a green color characteristic for vegetation. However, the image of woody and also grassy vegetation on color photographs is in poor detail: on photographs there is an inadequately clear differentiation of alluvial soils of the high and low floodplain -- soddy-gleyey and drier soddy gleyey soils, etc.

Spectrozonal color photographs have broader possibilities with respect to the discrimination of different soil varieties. The use of a spectrozonal survey increases the effectiveness of soil interpretation because soils can be interpreted in that spectral zone in which the differences in reflectivity are manifested most clearly. Vegetation and soils have a different reflectivity. Whereas for soils the greatest differences are observed in the spectral zone with a wavelength of 700 nm or more, for vegetation the greatest differences are in two zones: 520-600 and more than 700 nm. The photographing of the soil cover in these spectral zones increases the degree of their interpretability. Whereas on black-and-white panchromatic photographs light-gray clayey loam and light gray sandy loam soils show up in a uniform light gray tone, on spectrozonal photographs these varieties are characterized by a greenish-yellow color in the first case and a light yellow color in the second case.

On black-and-white photographs the areas of alluvial and meadow-chernozem soils with respect to tone usually merge with the image of dark gray forest soils and chernozems. These boundaries can be seen clearly on spectrozonal photographs.

C. Girard (1972), at the 12th International Congress of Photogrammetrists in Canada, reported that color spectrozonal aerial photographs have been used successfully in agriculture. They can be used in determining areas with different agricultural crops (grains, beets, alfalfa, potatoes, etc.). The reaction of plants to different applications of nitrogen fertilizers on the soil is clearly apparent. In individual cases on the basis of the nature of the image of one and the same crop it is possible to judge different precursors. In fields with mature grain crops it is easy to detect shortcomings in the chemical processing of the fields from the presence of weeds. On the basis of the presence or absence of weeds, clearly visible on the photographs, it is possible to judge the effectiveness of different methods for the weeding of agricultural crops. It is possible to establish the effectiveness of fallow because agricultural crops sown on fallow differ clearly from similar crops sown with different precursors. It is possible to discriminate plantings of perennial grasses in dependence on the year of use.

The use of color as an interpretation criterion and the surveying of the soil cover in a definite spectral zone made it possible to improve the interpretability of a number of soils in the dry-steppe zone from spectrozonal photographs: poorly developed chestnut, chestnut solonetz-like, meadow-chestnut, steppe solonetz soils formed on Paleogene clays, meadow-swampy or other soils. Dark chestnut, calcareous dark chestnut, eroded dark chestnut, meadow chestnut, steppe and meadow-steppe solonetz soils were interpreted better from photographs of the SN-23 type. Sandy loam dark chestnut, meadow solonetz, swampy, meadow swampy and meadow soils are determined more effectively from photographs of the SN-2M and SN-5 types (Polyakov, 1972).

On spectrozonal photographs, on the basis of change in color, it is easy to detect different humus content, calcareousness and change in the mechanical composition of the soil. Sandy and sandy loam soils appear light yellow or in a light green-yellow color; medium and highly eroded areas also have a light yellow or greenish-yellow color. With an increase in the content of humus and moisture in the soil there is a change in color from light green to dark green (in plowed sectors). Surface calcareousness of soils is manifested in light green and yellowish-light green tones.

An important advantage of spectrozonal photographs over black-and-white photographs is also that floodplain soils on the basis of their color show up more differentially. As an example we will examine black-and-white and spectrozonal aerial photographs of the territory of one of the floodplains of an experimental sector of the steppe zone.

Alluvial floodplain soils are formed under the influence of natural silt deposition by rivers. The analyzed floodplain is covered by sedge-meadow grass meadows with an admixture of meadow grasses of different species.

On a spectrozonal color aerial photograph a reddish-brown color corresponds to an alluvial meadow-swampy partially drained soil and a greenish-yellow color corresponds to an alluvial meadow-swampy soil (Fig. 9, see insert). On black-and-white photographs they have light gray and dark gray tones. In the area of alluvial swampy meliorated soils on spectrozonal photographs the reddish-brown and yellowish-green colors clearly reveal the difference in the degree of moistening of these soils. On black-and-white photographs this difference is difficult to trace from the gray and dark gray tones on spring, summer and autumn photographs.

Still another significant advantage of color spectrozonal photographs over black-and-white photographs is that in exploited areas different agricultural crops show up in different colors in dependence on the development stage (see Fig. 9 in insert).

On these photographs it is easy to discriminate sectors of soils with an open surface having a green color of different saturation. A reddish-brown color of different intensity corresponds to ravines with meadow-chernozem soils; the moister and denser the vegetation, the more saturated will be the reddish-brown color of its image.

In the maturity stage fields of grains have a greenish-yellow-brown color; fields of grasses (sweetclover, alfalfa) have a red-orange color; corn has a brownish color. A reddish-gray color (of different intensity) is observed for chernozems covered by young shoots of agricultural crops.

In conclusion we will cite experience in investigation of the interpretability of the soil cover from different types of color spectrozonal aerial photographs sensitive to different spectral zones, carried out in one of the sectors of the steppe zone.

An analysis was made of the entire visible zone of the spectrum characteristic for the three-layer color negative film TsN-3, the IR and red zones of the spectrum for the spectrozonal film SN-2M and the more sensitive film SN-6, the IR and green zones of the spectrum of SN-5 film, the green and red zones of the spectrum of SN-4 film, the green, red and IR zones of the spectrum of color spectrozonal film SN-23.

The soil cover of the analyzed territory is represented by highly leached chernozems, residual calcareous chernozems, solonetz-like chernozems, solonetz-like chernozems, and also meadow-chernozem and meadow-swamp soils.

On SN-6 and SN-5 spectrozonal photographs residual-calcareous soils are readily interpreted from a yellow-brown or greenish-brown color. On SN-5 aerial photographs areas with residual-calcareous chernozems have a more greenish color and are interpreted more clearly. On color (TsN-3) and spectrozonal photographs (SN-4) these soils appear homogeneous or in a dirty-green color and are interpreted with greater difficulty. On all types of spectrozonal photographs the areas of solonetz-like soils (in the case of their plowing) show up in a dark green color due to a high (~8%) humus content and heavy mechanical composition. Against the image background of these soils on the basis of light yellow spots there is reliable interpretation of areas of thin residual calcareous rocky chernozems. In sectors covered by scrub (blackthorn, hawthorn and other species) or under a sparse vegetation of different kinds of grasses, these soils are interpreted differently. On photographs from SN-4 film the dry steppe shows up in a light yellow color; from SN-6 and SN-23 film -- yellowish-greenish; from SN-5 -- light green.

Sectors covered with blackthorn had a brown color on photographs from SN-23 film, but on photographs from SN-4, SN-5 film -- a similar brownish-dark green color. The least differences in the vegetation cover of forest and scrubby-grassy vegetation were observed on color (TsN-3) and spectrozonal (SN-4) photographs. It is therefore more difficult to interpret soils from them.

[redacted]

Meadow-chernozem and chernozem-meadow soils are covered by forest vegetation (oak, pear, poplar and other species). On color (TsN-3) and spectrozonal photographs of the SN-4 type the image of these soils merge with the image of highly leached and residual calcareous chernozems; on spectrozonal photographs of the SN-5 and especially the SN-6 and SN-23 types this difference is sharper in the greenish-yellow-brown or greenish-red-brown color.

Meadow-swampy soils covered with meadow-swamp vegetation were formed on the lower part of slopes in mesodepressions. Areas of these soils showed up clearly on color and spectrozonal photographs of the SN-6 and SN-23 types. These sectors appeared to have less contrast on SN-4 and SN-5 photographs. An analysis of color and spectrozonal photographs of different types indicated that the best results of interpretation of the soil cover from the different color of the photoimage were obtained from photographs prepared from SN-6 and SN-23 spectrozonal film. The interpretation of soils of forested sectors was particularly reliable when using these photographs.

Thus, the color of the soil cover is a reliable interpretation criterion. However, it is necessary to take into account what type of film, color or spectrozonal, is used in interpretation. Depending on this, not only the color diagnostic criteria of the photoimage of the soil cover, but also the effectiveness of its interpretation will be different.

Specific characteristics of color of soil photoimage on space photographs. Color is an important interpretation criterion for the study of soils from space photographs. In the USSR the first color photograph of the earth was obtained on 8 August 1969 by the automatic station "Zond-7" using an aerial camera with a long focal length (400 mm) from a distance of 70,000 km.

During flight of the long-lived "Salyut" orbital station hand cameras were used in obtaining color photographs on which lateritic and ferralitic soils of tropical regions were clearly discriminated (Kravtsova, 1977).

Using color photographs obtained during flights of the "Gemini" and "Apollo" spaceships for desert territories of Africa and Asia with a well-exposed surface of the soil cover, on the basis of the color differences we easily determined the following soils. In the territory of the Namib desert in a survey in June 1965 from an altitude of 330 km on Kodak-Ectachrom film a reddish color corresponded to ridged deflatable and semiconsolidated sands and an almost white color corresponded to a pebbly-rocky type of soils of the tropical deserts. In the territory of the southeastern part of the Arabian Peninsula in a survey in August 1965 from an altitude of 180 km on Kodak-Ectachrom film a reddish color corresponded to ridged deflatable and semiconsolidated sands of the Rub'al-Khali desert and a reddish color with a blue hue corresponded to soils of the tropical deserts with sandy offshore bars; the soils of oases had a dark blue color and coastal lagoons and swamps had a still darker blue color.

In the territory of southwestern Morocco, in a survey in August 1965, from an altitude of 250 km, on Kodak-Ectachrom film a dark red color corresponded to mountainous red-brown and brown soils. On the photograph their eroded variants had a bright red hue. Cinnamon and gray cinnamon soils had a gray-yellow color, whereas the soils of oases had a dark blue color.

In our investigations we also carried out a comparison of the photoimages of the soil cover and agricultural crops of the steppe zone of the USSR on the basis of color and spectrozonal photographs taken from space in the autumn of 1975. On a color photograph southern chernozems are shown in a brown color and sandy loam and sandy chestnut soils, on the other hand, appear light brown; on a spectrozonal photograph the corresponding colors are violet and light violet. On a color photograph eroded chernozems had a light brown color; on a spectrozonal photograph -- light gray with a violet hue.

On spectrozonal photographs it was considerably easier to see differentiation of alluvial-meadow, moist meadow and meadow-swampy soils, represented by light violet, violet and dark green with a violet hue respectively. On color photographs these soils had marked differences of a green color. On spectrozonal photographs irrigated fields of winter wheat and alfalfa were interpreted with greater contrast from a bright green color, whereas an almost white color corresponded to rice fields prior to harvest.

In unirrigated fields winter wheat had a light green color with a violet hue; the slower the development of the winter sprouts of the winter crop, the brighter was the violet color. Fields with grasses were interpreted from a green color, whereas sectors of forest were interpreted from a dark green color on the image of an SN-8 spectrozonal photograph.

In a space survey, the same as in an aerial survey, the greatest effect in soil recognition was obtained from spectrozonal photographs.

New possibilities for the use of color as an interpretation criterion arose in connection with a multizonal survey. Color images can be obtained from multizonal black-and-white photographs by means of the additive method. For this purpose each of the zones during printing from black-and-white negatives is colored a definite color and when they are put together there is a synthesized color image with a natural or conventional color transmission. The MSP-4 optical-mechanical synthesizer has great possibilities in this respect. It makes it possible to obtain a color image of soils and planted crops with the use of those spectral zones where their differences are maximum.

Size and Shape of Photoimage of Soil Units

The size and shape of soil units are direct criteria. With respect to shape and size the soil units may be very different. These are not characterized by that clearly expressed definiteness which is observed for topographic, hydrographic and other terrain features. However, in a number of cases the size and shape of the units have a definite character. For example, in the interpretation of meadow-chernozem and meadow-chestnut soils associated with depressions and ravines it must be taken into account that the outlines of these soils are elongated. Meadow and meadow-chernozem soils of depressions in most cases form small areas with a circular or "blade" configuration.

The extent of the image of soil areas is dependent on the survey scale. It has been established that the limiting possibilities of each scale are determined by the film resolution, aerial camera objective, photopaper and human eye. The minimum measurement which can be represented on photographs at 1:50,000 is 5 m, 1:25,000 -- 2.5 m and 1:10,000 -- 1 m under the condition that the resolution of the photographs on the average is 10-12 lines/mm. With a resolution of the eye of 5 lines/mm in the work it is possible to use photographs enlarged $2-4^x$ or more $(8-10^x)$. With the use of enlarged photographs the interpretability of the soil cover of small complex sectors of the territory is improved and facilitated. In our investigations photographs with a scale 1:40,000-1:50,000, enlarged to 1:10,000-1:12,000, had easily identifiable soil units.

The shape of the soil units is perceived more readily and is interpreted more accurately with an increase in the perimeter of the unit and an increase in the contrast between the soil unit and the surrounding background. This is reflected in the accuracy of soil mapping (Platonenko, 1960).

Elements of the gully erosion (rills and gullies) are successfully interpreted from the shapes and sizes on aerial and space photographs. Gullies are represented on the photographs by a narrow, clearly defined zigzag shape. Due to the destruction of the soil cover, washing away of humus and laying bare of soil-forming rocks they are represented by a bright-light tone. On aerial photographs it is possible to discriminate all stages in gully formation from the change in shape and size of the image (Fig. 10).

On aerial photographs ravines have an elongated, somewhat sinuous dendritic configuration. The bottoms and slopes of the ravines are covered by vegetation. On aerial photographs the upper parts of ravines are usually represented by a uniform gray tone which corresponds to the image of less moisture-loving vegetation and the development of meadow or meadow-chernozem and meadow-chestnut soils. The middle and lower parts of the ravines are represented by a dark gray tone, which is caused by the development of denser moisture-loving vegetation. In a number of cases at the bottom of a ravine it is possible to see a thin sinuous dark line corresponding to the watercourse and ravine.

Along the slopes of gullies and ravines of different steepness and extent there are sectors of sheet erosion of the soil cover. The photographs show the extent of areas of slightly eroded and especially medium and highly eroded soils which usually have a configuration elongated along the gullies and ravines (Afanas'yeva, 1965; Lepeshev, Smeyan, 1975; Semenova, 1961). In the study of the size and shape of soil units, especially of complex and eroded territories, the use of the quantitative microphotometric research method is promising (Orlov, 1977; Yantush, 1963).

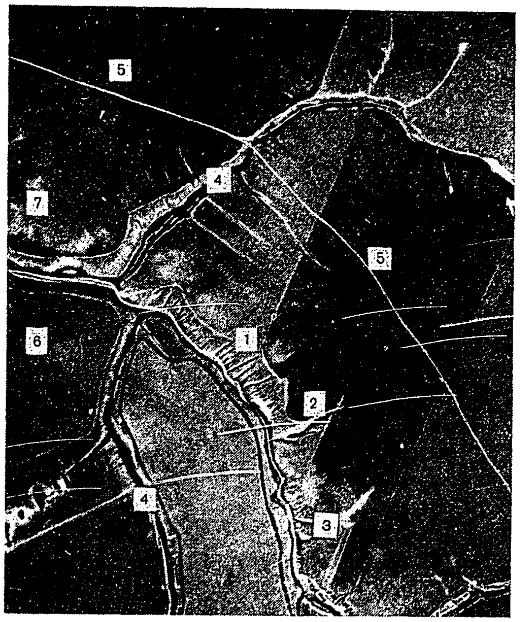

Fig. 10. Change in shape and size of image in dependence on different stages in gully formation and soil sheet erosion: 1) washed-out hollows; 2) "hanging gully" stage; 3) gully in stage of development of equilibrium profile; 4) ravines; 5) leached chernozem; 6) leached chernosem with slight sheet erosion; 7) leached chernozem with medium and heavy sheet erosion.

Figure 11 shows three microphotometric profiles characterizing the photoimage of ordinary chernozem, ordinary chernozem with slight and medium erosion and highly eroded chernozem. We note the different form of the microphotometric traces, related to the different nature of vertical erosional dissection and sheet erosion of the soil cover. The set of similar microphotometric traces and photoimages makes possible a more objective (with quantitative parameters) approach to the study and mapping of eroded soils from aerial and space photographs.

The materials of aerial and space surveys make it possible to trace the dependence of gully form horizontally on the form of the slope on which linear erosion develops. For example, linear, rhomboidal, bulb-shaped, lenticular and other forms of gullies can be traced successfully on photographs.

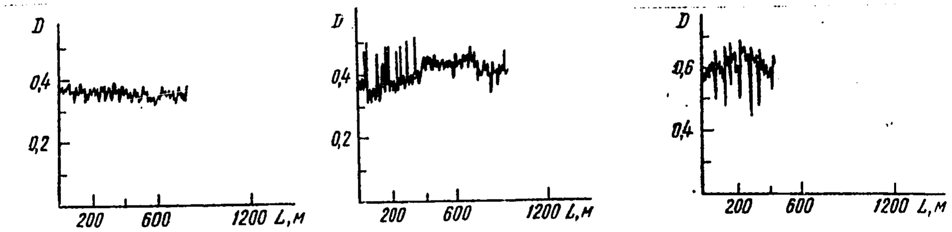

Fig. 11. Microphotometric soil profiles characterizing the photoimage of ordinary chernozem (top left), ordinary chernozem with slight and medium erosion (top right), ordinary highly eroded chernozem (bottom).

Characteristics of size and shape of photoimage of soils on space photographs. On space photographs at a scale of 1:1,000,000-1:2,500,000 in the steppe zone it is easy to determine natural regions with a different character of erosional dissection. The photographs show the main gullies, their lateral branches and sectors with an intensive growth of gully erosion.

In the territory of Kazakhstan and Western Siberia a light, almost white tone for a formation of small extent with a circular configuration corresponds to a solonchak (salina). Numerous lakes have a similar size and shape but a dark tone. As a rule, bitter salt lakes have a light-colored annular rim of shore solonchaks. Amidst sandy expanses, from the ridged form of the photoimage on space photographs, it is possible to give a successful interpretation of fine and coarse ridged sands. The photographs show that along the main direction of the prevailing winds the extent of the ridges can attain tens and hundreds of kilometers.

Regions which are agriculturally exploited are interpreted primarily from a checkered regular pattern of agricultural fields of a rectangular, square, polygonal form having a different image tone. On the basis of field size it is possible to discriminate unirrigated sectors having larger fields in the form of squares and rectangles, frequently of irregular configuration, and irrigated sectors with smaller fields having primarily a square shape of the image on space photographs.

In most cases the size and shape of the soil units are governed by the nature of the relief of the studied territory and serve as a component part of different patterns (textures) of the photoimage of the soil cover.

Texture (Pattern) of Photoimage of Soil Cover and its Classification

This criterion is the most stable and reliable in soil interpretation. It includes a different combination of sizes, shapes, tonalities or colors of the photoimage of the soils on aerial and space photographs. The chief advantage of aerospace materials in comparison with topographic and land surveying plans is that they characterize the spatial distribution of the soil cover. The structure of the soil cover is reflected only on aerial and space photographs. Aerospace photographs with the greatest completeness make it possible to study the geometry of structures of the soil cover, its composition, complexity, contrast, nature of the boundaries of elementary soil areas.

The characterization of structure provides for the description not only of the composition and components of the soil cover, but also a study of its interrelationships, processes of evolution and spatial pattern created by the soil units (Fridland, 1972). The materials of an aerospace survey, reflecting in detail the soil-vegetation cover of the earth's surface, make it possible to study the characteristics of structure of the soil cover complexly in interrelationship to other elements of the natural landscape.

Different types of spottiness of the soil cover are rather easily determined in plowed areas when materials from an aerial photographic survey are available. When these are not available the mapping of spottiness and complexes becomes time-consuming work which is very costly. V. M. Fridland (1972), in examining the problem of methods for studying the structure of the soil cover, points out that an effective method for compiling key profiles and maps necessary for the study of structure is the use of aerial photographs of different types and scales. The materials from an aerial photographic survey make it possible to discriminate not only areas of different combination structures of the soil cover, but also to discriminate elementary soil areas measuring up to 10-15 m. Elementary soil structures with the use of aerial photographs were discriminated in a detailed survey in the fields of the Kurskaya Agricultural Experimental Station (Sorokina, 1976).

In our investigations of the photoimage texture related to the structure of the soil cover we use a visual-instrumental quantitative method for the analysis of photographs with use of the "Kvantimet-720." Table 17 gives the morphometric indices of a two-component complex in the steppe zone, represented by meadow-steppe solonchak-like solonetz soils (situated on the main surface of the terrace) and chernozem-meadow solonetz-like soils on the bottoms of microdepressions. An analysis of the complex fine-spotted pattern of the photoimage was made for five areas of virgin land and three plowed areas (measurement variants) of a complex each with an area of 1 hectare (the KR and KS coefficients were both computed using formulas cited in a monograph by V. M. Fridland).

The "Kvantimet-720" instrument made it possible not only to obtain the quantitative characteristics of the photoimage of structure of the soil cover, represented by a two-component complex, but also to analyze the patterns of their spatial variation. For example, the plowing of virgin land sectors leads to a substantial change in the quantitative indices of their photoimage. During plowing there is a leveling of surface microrelief and a marked decrease in the number of small depressions. This is indicated by a decrease in the ESA (elementary soil area) number for chernozem-meadow soils and there is a simultaneous increase in their mean area. There is an evening-out of the boundaries of large ESA, which is manifested in a decrease in the total extent of the boundaries (total perimeter of the ESA), the mean value of the KR and a decrease in the complexity of the KS for the soil cover. (KS = complexity coefficient; KR = mean dissection coefficient)

L. A. Bogomolov (1976) describes an optical-geometric and genetic classification of the aerial photographic image of the textures of natural-territorial complexes. He discriminates homogeneous structureless, blurred and indefinite texture, sharp with a clearly expressed unordered texture, etc. Photographs are a means for storing soil-agricultural information. In this connection a new direction is developing -- study of the language of the photoimage of photographs by means of identification of characteristic structures. In the future it is realistic to expect an effect from the use of remote methods for study of automatic interpretation from spectral images and image texture.

On the basis of use of ERTS photographs specialists in the United States have tested machine analysis with the use of a combination of textural and spectral characteristics for the identification of lands of different categories of use (coniferous and hardwood forests, meadows, waters, irrigated lands). The accuracy in determination was 83.5%. Accordingly, study of the textures of the photoimage of the soil cover on aerial and space photographs and their classification, determination of the correlations between them and the structure of the soil cover is a necessary condition for the reliable interpretation of soils from aerial and space photographs.

As the basis for the classification of the textures of the photoimage of the soil cover on aerial and space photographs we used the difference in patterns in dependence on the geometry of the photoimage, spectral characteristics and genesis of the soils.

The largest subdivisions of textures of the soil cover were discriminated on the basis of the zonal-provincial principle. They include patterns of the photoimage characteristic for: arctic and tundra, forest, wooded steppe, steppe, dry steppe, desert and subtropical zones.

Depending on the degree of agricultural exploitation of the territories of the above-mentioned zones it is possible to discriminate the following categories of lands: 1) agriculturally exploited; 2) agriculturally exploited with some virgin lands; 3) virgin lands, poorly exploited lands.

Within the corresponding soil zone and category of lands there is a subdivision of textures (patterns) of the photoimage into classes in dependence on the conditions under which the soils are formed. The diverse textures of the photoimage of the soil cover are placed into four major classes (Fig. 12).

1. The textures (patterns) of the photoimage of the soil cover characteristic for automorphous, polymorphous and hydromorphous conditions (A, B).

2. Textures (patterns) of the photoimage of the soil cover characteristic for sectors subject to erosion (with subdivision into territories with the presence of wind erosion) (C, D).

3. Textures (patterns) of the photoimage of the soil cover characteristic for floodplain conditions (E).

4. Textures (patterns) of the photoimage of the soil cover characteristic for mountainous conditions.

Within these classes division into different types of textures is carried out in dependence on geometry: shape, size and spectral characteristics -- the different tone of the photoimage of soil units. It must be taken into account that there can be individual combinations of types of textures of the photoimage.

Textures of the photoimage of the soil cover determined from aerial photographs. Now we will examine different types of textures of the photoimage and their relationship to the nature of the soil cover.

1. For the automorphous conditions of the steppe zone the typical and ordinary chernozems of clayey loam mechanical composition are characterized by a monotonic structureless texture of dark gray or almost black tone (in the case of fresh plowing of the soils). The soil areas of extensive extent are frequently of an indefinite shape. This texture is characteristic for lowland and slightly undulating territories.

For southern chernozems and dark chestnut soils there is a typical point texture of a light tone related to the image of hillocks -- excavated calcareous soils on the photographs. Depending on the degree of this phenomenon it is possible to discriminate a point structure for southern chernozems and a thinnly spaced point structure (points less frequent by a factor of 3-4) for dark chestnut soils.

Relatively less common in the territory of the steppe zone is a curved-banded structure characteristic of the image of ridge and interridge depressions or related to unexpressed differences in the nature of the soil-forming rocks. As an example of the first case we can mention the image of southern thin pebbly calcareous chernozems formed on dense rocks in the territory of low ridges of the Syrtovoye Zavolzh'ye steppe. In the second case the appearance of a curved-banded texture is attributable to the image of calcareous clayey loam chernozem on the photographs, formed on calcareous rocks. The automorphous-hydromorphous conditions of the steppe zone are characterized by a spotty, dendritic and point-spotty texture of the photoimage. The appearance of this texture is related to the occurrence of meadow-chernozem (in the chernozem zone) or meadow-chestnut (in the chestnut zone) soils formed in circular or longitudinal depressions. In these cases spotty and dendritic textures have a dark gray or almost dark image tone. In the northern wooded steppe part, against the dark gray image background of podzolized and leached chernozems, the spotty texture can have a light gray tone related to the image of gray forest podzolized gleyey soils of depressions.

Now we will examine the textures (patterns) of the photoimage of the soil cover characteristic for halogene automorphous and hydromorphous conditions of the dry steppe zone. In general, for this class of textures there is a characteristic complex pattern consisting of a combination of granular, spotty-openwork, corrugated and trough-dendritic textures. For example, a three-component complex of dark chestnut solonetz-like, meadow-chestnut and meadow-steppe deep soils has a granular, fine-spotted openwork texture.

A dotted-corrugated, spotty-openwork texture is characteristic for a complex soil cover represented by meadow-steppe solonetz, solonetz-like meadow-chernozem, composite meadow-chernozem and meadow solonchak soils. A spotty-openwork structure is characteristic of the image of meadow solonetz soils against a background of chernozem-meadow solonetz-like soils. The image of alkaline podzols has a rounded-spotted texture. Meadow solonchaks on the photographs have a large spot, annular or arcuate texture of an almost white tone. The formation of annular or arcuate textures is associated with a soil cover which is formed around swales, swamps and lakes. In the dry steppe zone (chestnut soils) weedy solonchaks have formed along the shores of bitter salt lakes; then from the center to the periphery there are meadow solonchaks and beyond them -- solonchak-like meadow-chestnut soils.

2. The image of a soil cover subjected to water erosion on the photographs is characterized by the following textures. A low-contrast shallow-trough texture of a somewhat lighter tone than the surrounding watershed expanses is represented by slightly eroded chernozems formed on slightly convex slopes and ravines. Depending on the form of the slope this texture can acquire a fan-shaped character, for example, in the territory of the heads of gullies and ravines.

The following types of textures, which were discriminated from the increase in the degree of erosion of the territories, include striated-rill, striated-rill-gully, rill-ribbed-gully, rill-gully-ravine-dendritic. The formation of these textures is related to the development of linear and plane erosion and is characterized by the presence of slightly, medium- and strongly eroded chernozems. In the zone of occurrence of southern chernozems on long gentle slopes there is a dotted-troughlike texture. In the territory of the steppe Syrtovoye Zavolzh'ye the upper part of the watershed slopes is characterized by a dotted-striated-troughlike texture with slightly eroded southern chernozems. A banded-troughlike texture is typical for short convex slopes of watersheds and the depressions below the watersheds

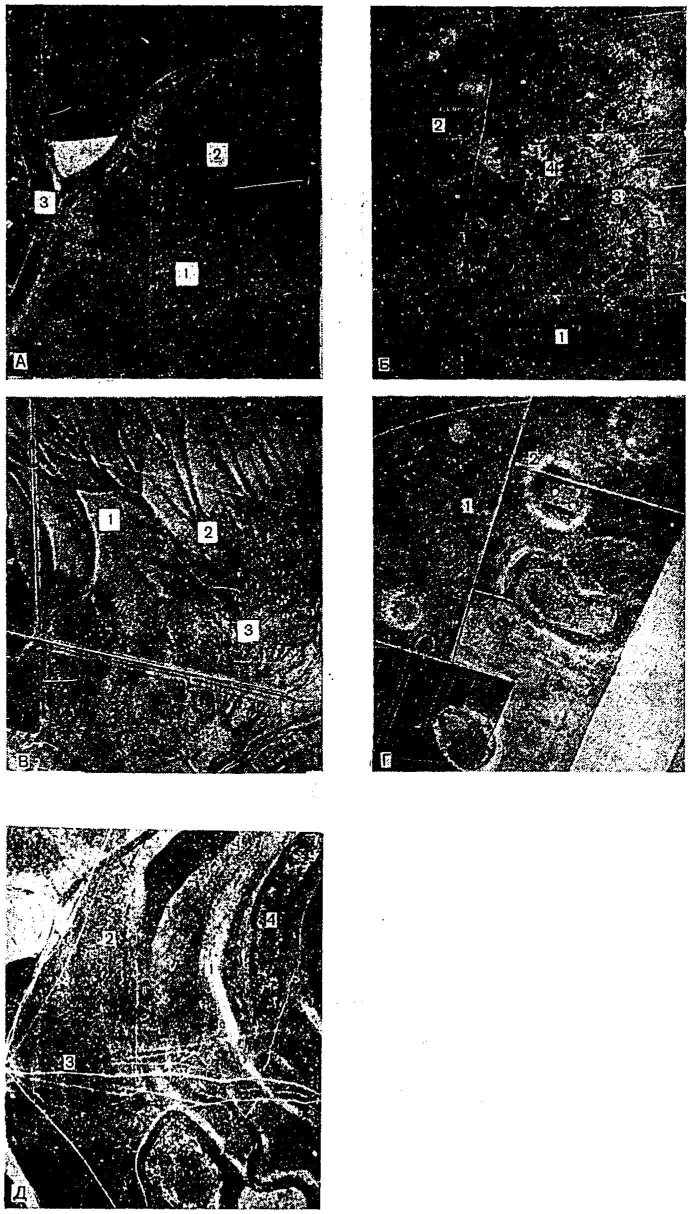

Fig. 12.

KEY TO FIGURE 12

A. Fine-spotted-dendritic (spots of a dark gray or almost black tone) texture of photoimage of soil cover from aerial photographs, characteristic for automorphous, polymorphous and hydromorphous conditions of steppe zone: 1) typical clayey loam chernozem; 2) meadow-chernozem clayey loam soil; 3) meadow-chernozem elutriated soil. B. Complex spotted-openwork-serrated and troughlike-dendritic texture (dark gray, gray and light gray tones) characteristic for halogene automorphous, polymorphous and hydromorphous conditions of dry steppe zone; 1) heavy clayey loam southern chernozem; 2) solonetzlike southern chernozem; 3) meadow-chernozem clayey loam soil; 4) steppe solonchak-like clayey loam solonetz soils. C. Troughlike-dendritic (dark gray, gray and light gray tones) texture of photoimage of soil cover subjected to water erosion: 1) clayey loam southern chernozem and slightly eroded southern chernozem; 2) meadow-chernozem clayey loam soil; 3) southern chernozem, calcareous, excavated soil at mouth of marmot burrows. D. Moiré-spotted-annular (light gray and almost white tone) texture of photoimage of soil cover subjected to wind erosion: 1) light clayey loam and sandy loam meadow-chernozem soil; 2) sandy, deflatable meadow-chernozem soil. E. Meandering-ox-bow-segmented (almost black, dark gray, gray, light gray and almost white tones) texture, characteristic for floodplain conditions: 1) alluvial sandy; 2) alluvial solonetz-like clayey loam soil; 3) alluvial moist-meadow clayey loam soil; 4) alluvial meadow-swampy clayey loam soil

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where slightly eroded southern chernozems and meadow-chernozem soils respectively are formed. Individual slopes of watersheds with southern excavated chernozems and southern eroded chernozems and meadow-chernozem soils in longitudinal depressions have a complex dotted-troughlike-dendritic photoimage texture.

The image of a soil cover subjected to plane water erosion (sheet erosion) is characterized by a spotty, curved-banded or circular-bladelike dendritic texture. The photoimage tone, due to sheet erosion of the soil layer containing humus, as a rule has a light gray or almost white tone. In places with active erosional activity the photoimage texture changes, acquiring a granular-ravined-dendritic (typical for sodded and forested slopes of ravines) or ravined-dendritic form (sodded ravines).

The image of a soil cover subjected to wind erosion has a spotty, spotty-wedgelike and spotty-moiré texture. The photoimage tone for the most part is light gray or almost white. Whereas the spotty and especially the wedgelike texture of a light gray tone is evidence of an active manifestation of wind erosion processes, the moiré pattern is typical for sandy loam and light clayey loam sand-permeated soils subjected to a small degree to deflation processes.

3. Among the textures (patterns) of the soil cover photoimage characteristic for floodplain conditions it is possible to discriminate segmental, meander-ox-bow lake, meander-spotty, estuary-large-spotted. For example,

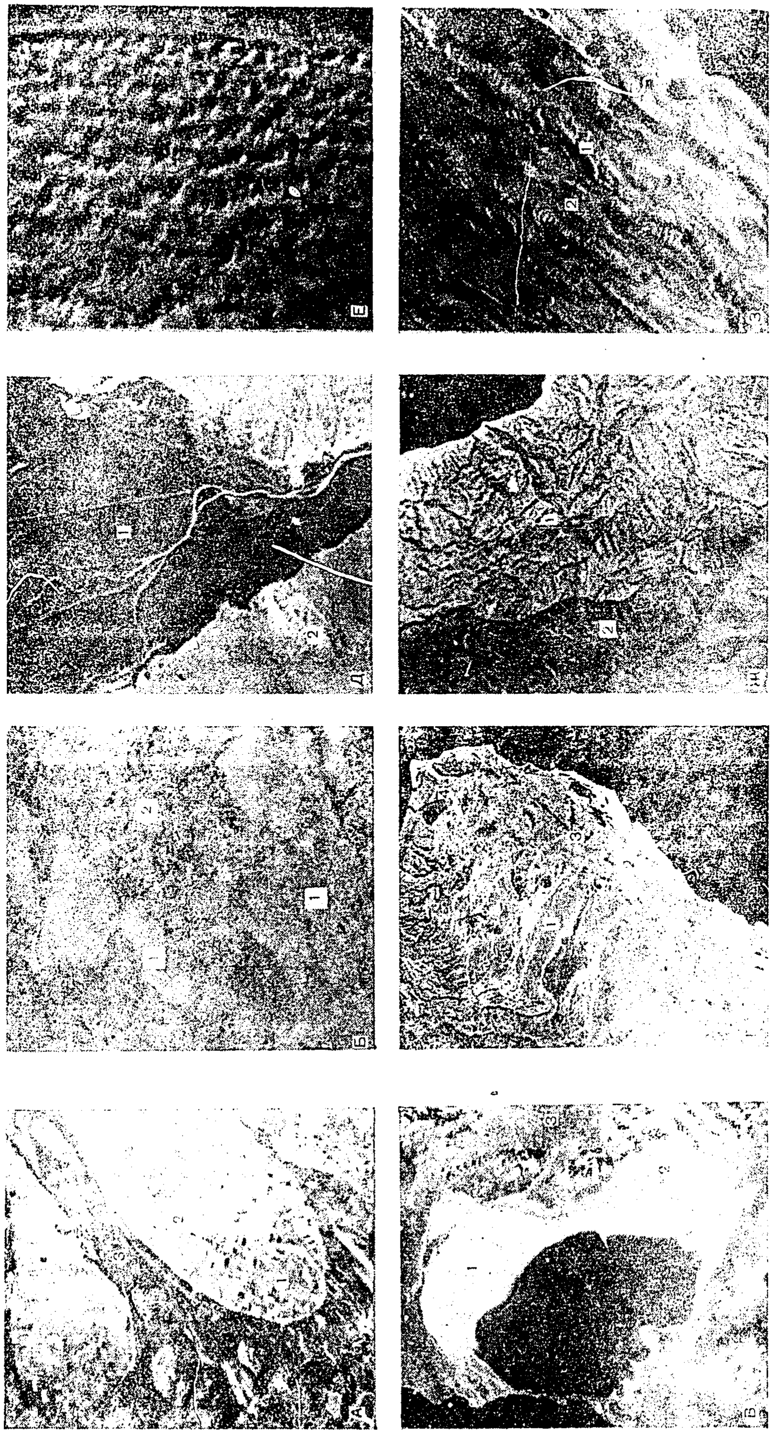

Fig. 13.

KEY TO FIGURE 13

A. Banded-spotty-mottled field (from almost white to a dark gray tone) photoimage texture of the soil cover from space photographs characteristic for the steppe and dry steppe zones (agriculturally exploited territories): 1) southern chernozems; 2) chestnut and steppe solonetz soils; 3) soddy-slightly podzolic (pinewood sands) with sectors of deflatable sands. B. Spotty-fanlike-mottled field (from light gray to almost black tone) texture, characteristic for desert zone (agriculturally exploited territories): 1) gray soils and gray-brown gypsum-bearing soils of desert plains; 2) irrigated gray soils and meadow-gray soils. C. Spotty-annular or arcuate (almost white, light gray or gray tone) texture characteristic for desert zone: 1) solonchak-salina; 2) meadow; 3) gray-brown desert soils. D. Spotty slightly striated-dry channel (gray, dark gray tone) texture characteristic for tropical deserts: 1) red-brown highly gravelly soils of desertified savannas; 2) soils of tropical deserts with banks along channels; 3) irrigated soils of oases; 4) coastal lagoons and swamps. E. Delta (gray or dark gray tone) texture: 1) alluvial irrigated; 2) sandy and rocky soils of subtropical deserts. F. Large-ridged (gray and light gray tone) texture of photoimage characteristic for ridged deflatable and semiconsolidated sands. G. Low-contrast complexly dendritic-crested (gray, light gray tone) texture characteristic for mountainous territories: 1) mountain red and reddish-brown soils of dry savannas; 2) reddish-brown highly gravelly desertified soils of savannas; 3) ridged deflatable and semiconsolidated sands. H. Spotty-banded-crested (from light gray to dark gray tone) texture characteristic for mountainous territories: 1) mountain gravelly gray soils; 2) gray soils and gypsum-bearing crusts; 3) salt domes

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a sharply contrasting segmental texture of an almost white tone is characteristic of alluvial sandy soils against a background of alluvial sandy loam and light clayey loam sand-permeated soils. A meander-ox-bow lake-segmental texture is typical for alluvial sandy, alluvial solonetz-like, clayey loam, alluvial moist meadow, alluvial meadow-swampy and ox-bow lake soils.

Alluvial meadow-swampy meliorated soils with a network of drainage canals have a meander-large spotty texture with regular linear-geometric sectors of different tonality. Alluvial swampy soils have a complex circular-spotty texture of different tone.

From an examination of these textures of the photoimage of the soil cover in the steppe zone on aerial photographs it can be seen that there are types which are encountered in all the principal classes of textures. These include a spotty texture. Depending on the soils forming it, it can be large-, medium- or small-spotty, circular spotty of different tone and contrast with the surrounding soils. This type is encountered rather frequently together with other, also rather widely occurring textures -- troughlike and dendritic.

In addition, it is possible to discriminate individual types of textures characteristic for a definite discriminated class. For example, class 1 of textures in the northern and central parts of the steppe zone is characterized by a monotonic-homogeneous form, in the southern part -- by a dotted form. For textures of the soil cover image characterizing halogene automorphous and hydromorphous conditions of the dry steppe zone it is typical to observe intricate complex textures consisting of granular, corrugated, openwork and annular types. For class 2 of textures characterizing a soil cover subject to water erosion it is typical to observe shallow trough, rill and troughlike dendritic forms; for soils subject to wind erosion there are spotty, wedgelike and moiré types of textures of a light or almost white tone. Finally, class 3 of textures of the soil cover image, characterizing floodplain conditions in the steppe zone, is represented by a segmental, meander-ox-bow lake form.

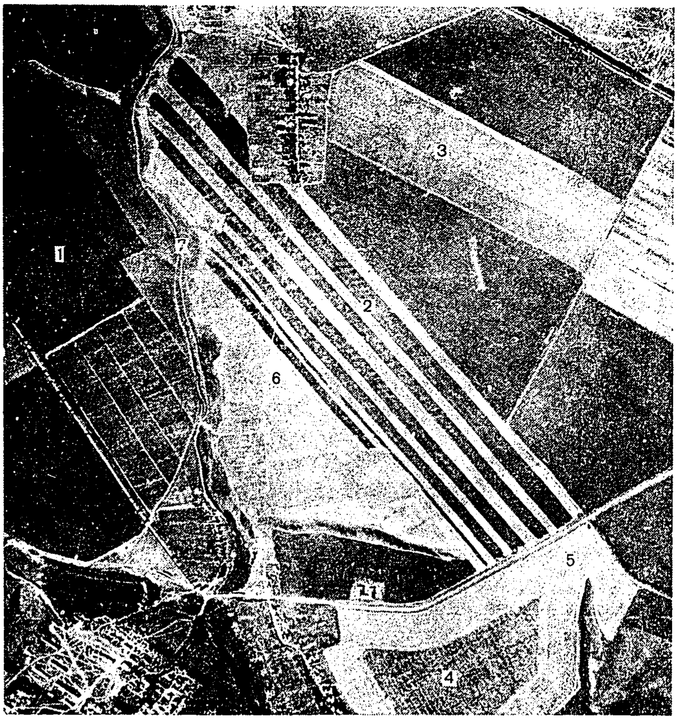

Fig. 14. Aerial photograph of territory of water divide and slopes along ravines in experimental sector of steppe zone. Survey time -- autumn: 1) winter wheat; 2) fall plowing; 3) potatoes (harvesting in progress); 4) corn; 5) stubble (after harvesting of corn); 6) stubble of grain crops; 7) pasture.

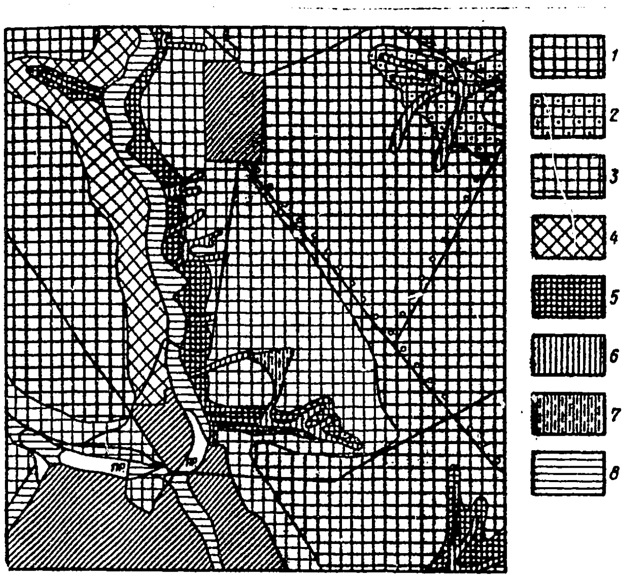

Fig. 14a. Soil map compiled from aerial photograph of the same territory of the experimental sector of the steppe zone: 1) typical thick chernozem with ordinary effervescence, typical thick chernozem with reduced effervescence and typical thick chernozem with ordinary effervescence on loessial clayey loam; 3) typical chernozem with ordinary effervescence, typical chernozem with reduced effervescence, marmot-excavated calcareous chernozem and slightly eroded typical chernozem on loessial clayey loam; 4) typical chernozem with ordinary effervescence, typical chernozem with reduced effervescence and slightly eroded typical chernozem on loessial clayey loam; 5) typical chernozem with ordinary effervescence, marmot-excavated calcareous chernozem and moderately eroded chernozem on loessial clayey loam; 6) meadow-chernozem leached soil on detrital clayey loam; 7) calcareous meadow-chernozem soil; 8) meadow-chernozem leached and elutriated soil on detrital clayey loam.

Textures of photoimage of soil cover from space photographs. On space photographs, like on aerial photographs, it is easy to see different types of photoimage textures reflecting the structure of the soil cover. One of the distinguishing characteristics of space photographs is that there is a considerable generalization of the detailed structure of the soil cover on them. Individual details of the soil cover structure are integrated and in generalized convex form there is manifestation of textures of the photoimage characteristic for individual soil-geographic regions. Many of the individual peculiarities of the features clearly visible on the aerial photographs are blended into the photoimage texture on the space photograph.

L. A. Bogomolov (1974) emphasizes that it is necessary to distinguish uncontrollable and controllable space optical generalization. Uncontrollable generalization is governed by the laws of optics and geometry and is dependent on the photographic scale and atmospheric absorption of the rays which travel from the soil cover to the survey instrument. In the case of controllable generalization by means of technical devices the initial photoimage can be transformed for a better clarification of the peculiarities of structure of the soil cover and fields of agricultural crops on space photographs.

We made an analysis of a soil map of the southern part of Iran at a scale of 1:2,500,000 compiled by M. S. Devan and a space photograph of this same scale. On the space photograph it is easy to trace a spotty-linear structure of the soil cover of this territory which is associated with mountain-ridge relief, an alternation of soil-forming rocks and the formation of numerous salt domes. In generalization on a soil map this typical nature of the soil cover was to a considerable degree lost. Accordingly, space photographs assist in refining soil maps and discriminating from them the types of structures of the soil cover on small-scale soil maps.

Now we will cite a number of typical textures of the soil cover photoimage on space photographs (Fig. 13).

The image of large solonchaks - salinas -- is characterized by a monotonic texture of an almost white tone which has very sharply contrasting boundaries with the surrounding soil units. Small solonchaks - salinas, or meadow solonchaks, amidst southern chernozems and chestnut soils are reliably determined on photographs from the sharply contrasting spotty or annular texture of the photoimage.

On space photographs gray and gray-brown desert soils have a monotonic structureless or low-contrast spotty texture of a gray or light gray tone. The photoimage of mountain soils is characterized by a different complexity of a dendritic-crested and spotty-banded-crested texture.

On space photographs it is very easy to see a ridged texture characteristic of the photoimage of deflatable and semiconsolidated sands. The photographs show that the extent of the sand ridges can attain hundreds of kilometers.

The image of the mouth sector of most rivers is characterized by a delta texture with alluvial soils. Depending on the nature of the soil cover it has a different degree of internal spottiness or a linear pattern characteristic for irrigated delta soils with the image of primary canals. A spotty-meandering texture of the photoimage on space photographs is characteristic of alluvial floodplain soils in river valleys.

On photographs the soil cover of territories in which agricultural crops are cultivated differs sharply in texture from virginland regions. Cultivated soils with different plantings in fields of agricultural crops on space photographs have a complex square-linear (sometimes an irregular form) texture of different tonality from almost white to almost black tones. Irrigated expanses of agricultural lands are also characterized by a complex square-rectangular photoimage (but of smaller and more regular sizes), corresponding to the cutting of the fields by melioration systems. The photoimage of irrigated fields situated on gray and meadow-gray soils of plains at the base of mountains and in the intermont basins of Central Asia is characterized by a fanlike texture of small squares and rectangles.

The image of complex texture of agricultural fields on photographs for the summer survey season hinders the successful interpretation of the soil cover in territories which are agriculturally exploited. However, from the different tonality of fields it is possible to determine different plantings of agricultural crops and their qualitative condition.

An analysis of space photographs indicated that in addition to the complex multifield square-rectangular image texture of fields of agricultural crops it is possible to determine a striated-gully-dendritic texture for the territory of highlands (Central Russian, along the Volga, and others) and trough-dendritic for plains areas. Both these textures of the soil cover image are related to the presence and different manifestation of the processes of water erosion of the soils.

From the pattern (texture) of the soil cover image on space photographs it is easy to distinguish categories of lands characteristic for agriculturally exploited areas: agriculturally poorly exploited or unexploited regions of the desert and semidesert zones (pasturing regions); the textures of modern and ancient deltas and photoimage textures characteristic for sands and the soil cover of mountainous areas are also discriminated.

We note in conclusion that the detection of different soil cover textures from space photographs can be used successfully in the compilation and refinement of a soil map of the world and individual continents with respect to the reflection of soil cover structures on them.

The image texture of soil-agricultural features on space photographs has its specific characteristics, related to generalization of individual details of the soil cover structure.

One of the most important tasks for the immediate future is an investigation of the soil textures of space photographs and their individual components making up the generalized photoimage. It must be remembered that one and the same (with respect to geometric form and dimensions) texture on an aerial and space photograph can have a different content and genesis. For example, a granular pattern of forests on aerial photographs is attributable to the image of individual crowns of trees; on a space photograph the granularity of forested areas (frequently poorly expressed) is attributable to differences in the species makeup, the image of individual curtains of trees, etc. As indicated by the first investigations made for the purposes of agriculture, study of the image textures of agricultural fields on space photos, it is possible to make a detailed, differentiated regionalization of individual regions of the country with respect to agricultural land use, land use and crop cultivation forms.

Table 15

Yield of Clover (Aftercrop) in Sectors With Different Fertility Levels (Wet Mass in Grams). Calculation Areas: 1 m^2. Determination Time 9 October 1975

Number of areas considered	Level I	Level II	Level III
1	1200	750	550
2	1100	820	620
3	1200	800	600
4	950	800	700
5	1200	700	500
6	1300	700	620
Mean	1160	760	600

Table 16

Tone of Photoimage of Principal Soils in the Steppe Zone on Black-and-White Isopanchromatic Aerial and Space (Normally Taken and Printed) Photographs (State of Air-Dry Soil Surface)

Photoimage tone	Soils
White	Solonchaks with salt crust on surface
Almost white	Crusted and fine solonetz soils during plowing of solonetz horizon; alkaline podzols during cultivation of podzolized horizon; calcareous excavated chernozems and excavated chestnut soils (at mouth of marmot burrows); highly eroded chernozems and chestnut soils on calcareous rocks; chernozems and chestnut soils, sandy, highly deflated; alluvial poorly developed sandy soils
Light gray	Medium and deep solonetz soils during plowing of solonetz horizon; chernozems and chestnut eroded soils; chernozems and chestnut sandy and sandy loam soils; chernozems and chestnut thin gravelly soils; alluvial meadow sandy soils
Gray	Chestnut and light chestnut clayey loam soils; calcareous chernozems with high level of effervescence and residual calcareous chernozems; chernozems and dark chestnut slightly eroded soils; meadow-chernozem and meadow-chestnut podzolized soils during plowing of podzolized horizon; meadow and alluvial-meadow soils with meadow vegetation
Dark gray	Podzolized, leached, typical, ordinary, southern chernozems; dark chestnut; meadow-swampy; alluvial moist-meadow and meadow-swampy soils with coverage by moist meadow vegetation
Almost black	Meadow-chernozem and meadow-chestnut soils of longitudinal troughs and swales with their plowing
Black	Chernozem-meadow and meadow soils of swales and alluvial-meadow dark-colored soils of heavy mechanical composition with their plowing

Table 17

Morphometric Characteristics of Photoimage of Two-Component Complex (Analysis of Elementary Soil Units of Chernozem-Meadow Solonetz-like Soils Against Background of Meadow-Steppe Solonchak-like Solonetz Soils) (With Participation of V. S. Stolbovoy)

Land use area, elementary soil units	Варианты измерений на 1 га 1	Доля участия ЭПА в комплексе, % 2	Количество ЭПА 3	Средняя площадь ЭПА 4	Максимальная площадь ЭПА 5	Суммарный периметр ЭПА, м 6	Средний коэффициент расчленения (КР) 7	Коэффициент сложности (КС) 8
				м²				
Virgin land, chernozem-meadow solonetz-like soils	1	20,6	29	75	440	1150	7,0	0,12
	2	23,8	34	74	440	1230	7,0	0,11
	3	20,7	32	69	200	1260	7,7	0,14
	4	22,2	29	81	310	1290	7,2	0,12
	5	21,5	34	67	440	1140	6,9	0,12
Cultivated land, chernozem-meadow solonetz-like soils	1	19,8	10	210	540	760	4,7	0,08
	2	22,9	6	405	540	713	4,8	0,08
	3	18,5	12	163	500	740	5,1	0,09

KEY:

1. Variants of measurements per 1 hectare
2. Fraction of participation of elementary soil unit in complex, %
3. Number of elementary soil units
4. Mean area of elementary soil unit
5. Maximum area of elementary soil unit
6. Total perimeter of elementary soil unit, m
7. Mean breakdown coefficient
3. Complexity coefficient

Table 18. Interpretation Criteria for Soils of Steppe Zone of Mongolia* (Table-Key). Survey Period Summer. Aerial Photographs Black-and-White Medium Scale - Isopanchromatic Film

	Soil	Relief	Vegetation	Глубина образца, см 1
			7 *Почвы горных*	
9	Горные каштановые маломощные щебнистые	Гребни горных хребтов и крутые части южных склонов 22	Полынно-злаковая с широким участием петрофитов 35	0—10 20—30
10	Горные каштановые среднемощные	Горные склоны южной экспозиции 23	Полынно-злаковая 36	0—10 30—40
11	Горные темно-каштановые	Горные склоны северной экспозиции. Абс. высота 1380—1500 м 24	Полынно-злаковая 37 с участием разнотравья	0—10 20—30 50—60
12	Горные черноземы	Горные склоны северной экспозиции. Абс. высота 1500—1800 м 25	Полынно-злаково-разнотравная 38	0—10 20—30 40—50
13	Горные лугово-лесные	Замкнутые котловины-цирки верхней части северных склонов 26	Островные березо-осиновые леса 39	2—10 20—30 32—42
			8 *Почвы увалистых равнин*	
14	Каштановые маломощные щебнистые	Вершины увалов и участки крутых склонов 27	Полынно-змеевково-ковыльная сухая с участием петрофитов 40	0—10 25—35 40—50
15	Каштановые среднемощные	Склоны увалов межгорных котловин, слабоволнистые участки высоких равнин 28	Полынно-змеевково-ковыльная сухая с караганой 41	0—10 25—35 35—45
16	Каштановые солонцеватые	Плоские участки равнины с выраженным микрорельефом 29	Полынно-осоково-злаковая сухая 42	0—10 13—26 45—55
17	Каштановые высско-вскипающие	Предгорные шлейфы и нижние склоны межгорных котловин 30	Полынно-змеевково-ковыльная сухая с караганой 43	0—10 25—35 50—60
18	Лугово-каштановые	Ложбины внутри горных котловин 31	Злаково-разнотравная 44	0—10 30—40 70—80
19	Лугово-каштановые остепняющиеся	Ложбины увалистых равнин 32	Разнотравно-злаковая с участием чия 45	0—10 26—36 40—50
20	Луговые солончаковые	Глубокие участки ложбин и периферийные части западин 33	Луговое разнотравье, чий, ирис и др. 46	0—10 20—30 50—60
21	Солончаки	Дница западин 34	Солончаковая растительность (сведа, поташник и др.) 47	0—2 2—10 35—45

pH водной 2	Гумус 3	CaCO$_3$	Сумма солей 4	Крупнозем 5	Частицы (%) размером, мм		6 Tone, pattern and other photoimage criteria
	%				<0,001	<0,01	
территорий							
8,1	1,5	0,4	—	14	1	9	Светло-серый с ярко-светлыми пятнами осыпей, границы резко контрастные 48
8,6	0,9	1,6	—	95	—	—	
6,5	3,0	0,0	—	51	6	12	Мелкопятнистый рисунок светло-серого и серого тона 49
6,8	2,1	0,2	—	53	2	18	
6,3	3,9	—	—	23	1	11	Однородный серый тон 50
6,9	2,0	—	—	37	1	17	
7,2	0,9	—	—	15	4	21	
6,6	4,5	—	—	16	5	15	Однородный темно-серый тон 51
6,4	3,0	—	—	30	4	13	
6,6	2,5	—	—	33	4	10	
6,7	13,2	—	—	—	1	11	Пятна темного тона с резко контрастными границами 52
6,4	7,2	—	—	9	3	16	
6,3	2,2	—	—	15	6	26	
и межгорных котловин							
7,6	2,0	0,0	—	33	3	9	Светло-серый тон 53
7,7	1,0	0,0	—	18	1	5	
8,4	—	13,4	—	52	12	21	
6,3	2,5	0,0	—	28	4	19	Светло-серый и серый тон пятнистого рисунка, границы контуров слабо контрастны 54
7,4	2,0	0,7	—	41	5	11	
7,9	1,4	10,7	—	38	3	12	
6,6	1,6	0,0	—	15	9	20	Серый тон, муаровый рисунок 55
8,3	1,2	0,0	—	3	9	21	
9,4	0,9	5,7	—	—	13	36	
7,7	2,3	0,7	0,05	5	1	1	Серый тон, струйчатый рисунок 56
8,0	2,3	32,7	0,06	8	15	33	
8,2	0,4	36,4	—	18	17	40	
7,0	3,2	0,0	—	5	8	10	Серый и темно-серый тон, вытянуто-пятнистый рисунок, контуры линейно-древовидные, границы контрастные 57
7,2	2,4	0,8	—	4	19	21	
8,9	1,4	1,6	—	5	14	30	
6,8	3,1	0,4	0,04	16	11	27	Серый тон, контуры линейно-древовидные, границы контрастные 58
7,9	2,8	20,3	0,05	14	—	18	
8,3	0,9	22,7	—	19	21	30	
8,2	10,8	34,5	0,72	Нет	6	16	Темно-серый тон, форма контуров округло-линейная, границы резко контрастные 59
8,0	4,4	44,3	0,07	»	12	38	
8,1	3,2	36,0	0,06	»	36	44	
9,1	1,6	2,5	3,60	»	6	17	Ярко-светлый тон, округлая форма контуров, границы резко контрастные 60
9,4	1,6	6,7	1,66	»	15	31	
9,2	0,6	10,6	1,72	»	40	64	

Soil	Relief	Vegetation	Глубина образца, см 1
61 Пески	65 Приречные склоны гор	69 Псаммофиты (астрагал, элимус и др.)	0—10 30—40 55—65
			73 *Почвы*
62 Аллювиальные (пойменные) луговые	66 Плоские и грядовые участки центральной поймы	70 Злаково-разнотравно-луговая	0—10 10—20
63 Аллювиальные (пойменные) лугово-болотные	67 Заросшие старицы и протоки центральной и притеррасной поймы	71 Разнотравно-луговая с участием болотных видов и тростника	0—10 25—35
64 Аллювиальные (пойменный) солончак	68 Отдельные участки притеррасной поймы	72 Лугово-солончаковая	0—2 2—10 10—20

* Таблица составлена совместно с Г. А. Шершуковой.

*Table compiled jointly with G. A. Shershukova.

KEY TO TABLE 18

1. Depth of sample
2. pH aqueous
3. Humus
4. Sum of salts
5. Coarse earth
6. Particles (%), size mm
7. Soils of mountain areas
8. Soils of ridged plains and intermont basins
9. Thin gravelly mountain chestnut
10. Medium-thick mountain chestnut
11. Mountain dark chestnut
12. Mountain chernozems
13. Mountain meadow-forest
14. Thin gravelly chestnut
15. Medium-thick chestnut
16. Solonetz-like chestnut
17. Chestnut with high effervescence
18. Meadow-chestnut
19. Steppized meadow-chestnut
20. Solonchak-like meadow
21. Solonchaks
22. Crests of mountain ranges and steep parts of southern slopes
23. Mountain slopes of southerly exposure
24. Mountain slopes of northerly exposure. Absolute elevation 1,380-1,500 m
25. Mountain slopes of northerly exposure. Absolute elevation 1,500-1,800 m
26. Closed basins-cirques of upper part of northern slopes
27. Peaks of ridges and sectors of steep slopes
28. Slopes of ridges of intermont basins, slightly undulating sectors of high plains
29. Flat sectors of plain with well-expressed microrelief
30. Alluvial fans and lower slopes of intermont basins
31. Longitudinal troughs within mountain basins
32. Longitudinal troughs of ridged plains
33. Deep sectors of longitudinal troughs and peripheral parts of swales
34. Bottoms of swales
35. Wormwood-grass with broad participation of petrophytes
36. Wormwood-grass
37. Wormwood-grass with participation of mixed grasses
38. Wormwood-grass-mixed grass

Table 18 (continued)

pH водной 2	Гумус 3	$CaCO_3$	Сумма солей 4	Крупнозем 5	Частицы (%) размером, мм 6		Tone, pattern and other photoimage criteria
	%				0,001	0,01	
6,8	0,6	0,0	—	—	—	6	Ярко-светлый тон, ячеисто-грядовый рисунок, границы резко контрастные 74
7,5	0,9	0,0	—	17	2	8	
8,0	0,3	0,2	—	2	2	6	
поймы							
7,3	2,7	0,0	—	—	7	17	Серый тон, меандровый рисунок, граница контрастная 75
9,4	2,0	2,5	—	Нет	6	20	
				78			
7,7	4,7	4,5	0,12	»	3	8	Темно-серый тон, веерно-меандровый рисунок, граница нейтральная 76
6,4	0,7	0,0	0,03	»	3	17	
10,0	0,6	4,3	1,00	32	6	14	Ярко-светлый тон, округло-пятнистая форма, граница резко контрастная 77
10,1	0,7	7,3	0,63	17	14	24	
9,3	0,6	8,2	0,68	11	5	16	

KEY TO TABLE 18 (continued)

39. Island birch-aspen forests
40. Wormwood-bistort-feathergrass (dry) with participation of petrophytes
41. Wormwood-bistort-feathergrass (dry) with caragana
42. Wormwood-sedge-grass (dry)
43. Wormwood-bistort-feathergrass (dry) with caragana
44. Grass-mixed grass
45. Mixed-grass-grass with participation of Lasiagrostis
46. Mixed meadow grasses, Lasiagrostis, iris, and others
47. Solonchak vegetation (seepweed, Russian thistle, etc.)
48. Light gray with bright-light spots of talus, boundaries sharply contrasting
49. Small-spot pattern of light gray and gray tone
50. Uniform gray tone
51. Uniform dark gray tone
52. Spots of dark tone with sharply contrasting boundaries
53. Light gray tone
54. Light gray and gray tone of spotty pattern boundaries poorly contrasting
55. Gray tone, moire pattern
56. Gray tone, striated pattern
57. Gray and dark gray tone, elongated-spotty pattern, soil units linear-dendritic, boundaries contrasting
58. Gray tone, units linear-dendritic, boundaries contrasting
59. Dark gray tone, form of units rounded-linear, boundaries sharply contrasting
60. Bright-light tone, rounded form of soil units, boundaries sharply contrasting
61. Sands
62. Alluvial (floodplain) meadow
63. Alluvial (floodplain) meadow-swampy
64. Alluvial (floodplain) solonchak
65. Mountain slopes along rivers
66. Flat and ridged sectors of central floodplain
67. Overgrown ox-bow lakes and channels of central and near-terrace floodplain

KEY TO TABLE 18 (continued)

68. Individual sectors of floodplain near terrace
69. Psammophytes (milk vetch, wildrye, etc.)
70. Grass-mixed grass-meadow
71. Mixed grass-meadow with participation of swampy species and reeds
72. Meadow-solonchak-like
73. Floodplain soils
74. Bright-light tone, cellular-ridged pattern, boundaries sharply contrasting
75. Gray tone, meander pattern, boundary contrasting
76. Dark gray tone, fanlike-meander pattern, boundary neutral
77. Bright-light tone, rounded-spotty form, boundary sharply contrasting
78. None

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Relief, Hydrographic Elements and Their Role in Soil Interpretation

In soil interpretation on the basis of aerial and space photographs relief and hydrographic elements serve as important indicators for soil interpretation.

The value of aerial and space materials is that on these photographs relief and individual hydrographic elements show up with great objectivity and detail. On aerial photographs at large and intermediate scales there is a diversity of relief forms. Using stereoscopic instruments and stereopair photographs the soil scientist is able to obtain a stereoscopic relief image. A knowledge of the interrelationships between the soil, relief forms and types, makes it possible to use this stereoscopic relief image as a means for interpreting the soil cover. S. Mike (1972) notes that a complex method for relief analysis, which is based on allowance for the different nature of slopes and other geomorphological elements, makes possible a correct determination of genetic types of soils, favoring a precise mapping of types of soils.

On aerial photographs of the steppe zone it is easy to discriminate swales, longitudinal runoff troughs, rills, gullies, ravines, hills, ridges, different forms of slopes near ravines and on watersheds, water divide areas and other elements of meso- and microrelief. Relief is one of the landscape elements through whose image we indirectly determine soils under office and field conditions (Liverovskiy, 1957; Kalnina, 1965, 1971; Simakova, 1959; Tolchel'nikov, 1966). In the steppe zone meadow-chernozem and meadow-chestnut soils are successfully interpreted from their association with longitudinal troughs and swales, whereas alluvial (floodplain) soils are successfully interpreted due to their association with river floodplains. Floodplains with different degrees of flooding are distinguished. A high, rarely flooded floodplain is characterized by a uniform even image tone; a low floodplain is characterized by a considerable dissection of the surface, a well-developed network of watercourses, ox-bow lakes and cutoff meanders.

It is exceptionally important to take relief into account in organizing the territory in erosionally dangerous regions. The best basis for this, as indicated by our work on compilation of a soil map of one of the farms in Orenburgskaya Oblast, is aerial photographic plans plotted in contours. Under office conditions they make it possible to judge the exposure and slopes of the analyzed territory and simultaneously the nature of sheet, linear and wind erosion of soils. In addition to the steepness and exposure of the slopes, from photoplans with contours it is possible with success to take into account the length and form of the profiles of the slopes, as well as the nature of dissection of the territory of the gully and valley-ravine network. In order to determine the degree of sheet erosion of the soil it is important to take into account rills, longitudinal troughs and gullies, which are detected on photographs with a great accuracy. The considerable sheet erosion of soils in Orlovskaya, Kurskaya, Voronezhskaya, Saratovskaya, Penzenskaya and other oblasts in the steppe zone is related to the number of rills per unit area. These forms of linear erosion are also easily interpreted from the number and also the degree of expression of the rills, which makes it possible to use the photographs in discriminating on the soil map areas having different degrees of erodability of territories.

The method of instrumental interpretation of eroded soils makes it possible to determine the quantitative dependences of erosion processes on a number of factors: steepness, length, form, exposure of slopes, types of basins, nature of microrelief. The use of materials from an aerial photographic survey — contact and enlarged photographs, photomosaics, photoplans — makes it possible to determine the principal characteristics of erosional processes.

The use of photographic materials and stereoscopic instruments can be of value in measuring the rate of growth of gullies and in determining their age. Using aerial photographs for a number of years for one and the same territory (Chervyakov, 1963) it is possible to determine the rate of gully growth using the formula:

$$V = \ell_m - L/n \quad \text{m/year},$$

where L is a segment measured in the field from the bottom of the gully to some contour point in the direction of gully growth, visible on the photograph; ℓ is the corresponding segment measured on the aerial photograph; m is the denominator of the photograph scale; n is the number of years elapsing after the aerial photographic survey.

By determining the rate of gully growth it is possible to determine its age using the formula

$$T = L_0/V,$$

where L_0 is gully length; V is the rate of gully growth. The data obtained on the mean annual growth of the gully network can be used in regionalizing the territory on the basis of erosion intensity.

Aerial photographs and stereoscopic measuring instruments make it possible to measure such an important index of relief as slope steepness. For example, a map of slopes obtained from a photoplan was used by N. N. Semenova (1962) for compiling soil-erosion maps for individual sectors of the Tsimlyanskoye and Kuybyshevskoye Reservoirs.

An analysis of relief from aerial photographs makes it possible to study the dynamics of soil erosion processes. For this it is desirable to use photomaterials obtained a second time for one and the same territories after a definite number of years. In an analysis of aerial photographs of one and the same territory of the Central Russian Highland in the steppe zone, obtained at an interval of 10 years, we established that a high percentage of the erosionally dangerous processes remained unchanged. Some of the small gullies and the upper parts of the gullies are overgrown with woody-scrub vegetation. Moreover, from the change in one of the gullies it is easy to see the direction of growth of a gully and the area affected by its new branchings.

Applying the principle of geographic analogues, it is possible to predict that this gully (if effective measures are not taken for protecting soils against erosion) will develop into similar gully-ravine areas situated alongside on this same slope, unsuitable for agriculture. On the basis of the nature of the relief shown on the photographs it is possible to distinguish sandy and clayey rocks. For example, the sandy slopes of ravines and the bedrock banks of rivers, wind-worked curvatures of slopes and their brows on the photographs have a flat-rounded configuration of a light gray or almost white tone. Steep unstable slopes with landslides are characteristic for clayey soils. Deep and narrow gullies and deeply incised rills are usually characteristic for loessial soils.

A near-vertical aerial photographic survey makes it possible to discriminate different types of branching of the gully-ravine network and to establish the dependence of branching on the form of the drainage basin. In this connection this material, covering considerable areas, makes it possible to judge graphically about the different types of erosional dissection.

Thus, an analysis of relief and hydrographic elements from aerial photographs gives some idea not only concerning the forms of linear erosion and different stages in the formation of gullies, but also serves as objective material for characterizing different types of soil-erosional dissection of our country and in studying the dynamics of erosional processes.

Specifics of the use of relief and hydrographic elements in the interpretation of soils on space photographs. Hydrographic and relief elements play an exceptionally important role in the interpretation of the soil cover from space photographs.

In contrast to ordinary aerial photographs an important characteristic of space photographs is that their identification and geographic tie-in to the terrain can be accomplished in a comparison with physiographic maps at a small scale. A comparative analysis of space photographs and existing small-scale maps shows that the clearest identification of space photographs is possible from the character of the shoreline, the pattern of the hydrographic network, the presence of lakes, intermontane depressions, large dry wadis, depressions, etc.

However, it must be taken into account that the elements of hydrography and relief may coincide only in general features with the image of space photographs. In details there can be discrepancies and even omissions of individual indicators. For example, in a part of the territory of the United States bounding on Mexico it was possible to use space photographs in compiling a land use map at a scale of 1:1,000,000. Using the space photographs it was possible to refine the position of agricultural lands, the image of roads, lakes and other features. On the earlier compiled small-scale materials about 200 characteristic terrain details which showed up on the photographs were missing.

Depending on the scale of the space photographs, there is an optical generalization of small relief details on the earth's surface on them. The principal most general patterns of structure of the earth's surface are manifested more sharply. As we established, on medium-scale and especially on small-scale space photographs in an optically generalized form there is a clear representation of individual elements of geotexture and morphostructure of the earth's surface, that is, the largest first- and second-order relief elements. The elements of morphosculpture, which constitute the basis for indirect interpretation of soils on the basis of materials from an aerial photographic survey, frequently cannot be seen on space photographs.

On small-scale space photographs of the territory of the Kazakh SSR, obtained during work of the orbital station "Salyut-4," as demonstrated by our investigations, there was clear representation of the soil cover, relief and hydrographic elements of large natural regions and physiographic regions of Kazakhstan. On the basis of the different photoimage tone and pattern there was reliable interpretation of a gently stepped plain with strips of pine forests in the neighborhood of Semipalatinsk, an intermontane basin with Lake Zaysan, the Betpak-Dala desert and the territory of the Kazakh low hill complex, the ridged sands of the Muyonkum, the valleys and floodplains of the Syrdar'ya, Chu, Ili Rivers, Karatau and Tarbagatay Ranges, southwestern spurs and ranges of the Altay.

On a space photograph of the territory of Kazakhstan, on the basis of the different image phototone it is easy to interpret the difference between the northern and southern part of the clayey Betpak-Dala desert. The low-lying southern part of the desert, adjacent to the valley of the Chu River, with gray-brown desert soils, steppe solonetz soils, gray soil takyrs and takyrs, has a light gray image tone. The northern, more elevated part of the desert (absolute elevation 200-300 m) has a dark gray image tone with individual infrequent spots of a light gray tone (takyrs and takyr soils). The photoimage of the eastern part of the desert (to a considerable degree rocky) is characterized by a mottled pattern of a gray and dark gray tone, emphasizing the inhomogeneous structure of the soil cover in this territory.

Areas of sands are represented by a uniform dark gray tone (Aryskum, Muyunkum, Zhetykonyr, and other sands). The photoimage of Muyunkum sands, situated to the south of the Chu valley, is characterized not only by a gray and dark gray image tone, but also by a typical ridged pattern of image relief.

The Muyunkum desert is geomorphologically closely related to the Chu valley, having a clearly expressed floodplain and two terraces above the floodplain, gradually undergoing transition into eolian desert plains. From a

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space photograph there is reliable interpretation of the northern edge of the valley of the Chu River with the Betpak-Dala desert and an alternation of narrowed and broadened sectors of the floodplain characteristic for the lower reaches of the Chu River. The broadened sectors constitute intravalley deltas formed in tectonic troughs. The soil cover is represented by gray-brown desert soils, solonetz soils, takyrlike gray soils (light gray tone), meadow-swamp solonchak-like soils (gray and dark gray tone), solonchaks (light tone). In the depressions there are many small lakes with a bordering edge of reeds and sedge meadows. On a photograph they have a pattern of small spots with a dark tone. The depth of soil-ground water can be determined for such territories (Abrosimov, Vostokova, 1973).

The Kopet-Dag Range with gray soils and the valley of the Syrdar'ya River with alluvial soils stand out sharply on a space photograph.

From a space photograph it is easy to interpret the boundary between the central part of the Kazakh hill country (light tone) and the territory surrounding Lake Balkhash, having a gray and dark gray image tone and a very complex erosionally dissected structure. Small sand hills show up in a uniform pattern in a dark gray tone.

The photograph image changes sharply to the south of Lake Balkhash. The Bestas area of ridged sands can be interpreted between the ancient delta of the Ili River and the Karatal River on the basis of the gray and dark gray tone and the fine-ridged structure of the relief image. The most moistened sectors of sands are shown as dark spots against a general gray background. Along the shore areas of solonchaks appear as bright-light spots and meadow-swampy solonchak-like soils appear in a dark tone due to the image of meadow-swamp vegetation.

A space photograph gives a clear discrimination of the territory of the modern delta from the ancient delta of the Ili River, cut by a network of dying channels with an alternation of ridged-hilly sands, takyr gray soils and takyrs. The modern delta of the Ili River with its numerous distributaries is characterized by floodplain overgrowths of willow and elaeangus, reed and mixed-grass meadow vegetation. On the photograph these sectors of the delta have a dark tone of the floodplain-meander photoimage pattern. The soil cover is represented by meadow-swampy solonchak-like soils, solonchaks and gray soil takyrs.

Our analysis of small-scale space photographs taken from the "Soyuz-9" spaceship in June 1970 and "Soyuz-12" in September 1973 for the Caspian Sea region demonstrated that amidst the individual elements of geotexture and morphostructure of the considered natural region it is easy to see the eastern part of the Caucasus Mountains with mountain brown forest and mountain cinnamon and gray-cinnamon soils and the northwestern spurs of the Kopet-Dag with mountain gray soils. On the space photograph it is easy to interpret the Prikaspiyskaya and Turanskaya Lowlands with gray-brown desert sandy soils and poorly consolidated sands. Against this background it is easy to see the Ustyurt Plateau with gravelly gray-brown desert clayey and heavy clayey loam soils. On the basis of photoimage tonality and pattern it was possible to detect negative relief forms -- salinas and depressions (Barsakel'mes, Mertvyy Kultuk, Kaydak and others) with solonchaks and meadow-swampy solonchak-like soils, and also the valleys and deltas of the Volga, Ural, Amudar'ya, Kura and Terek Rivers with alluvial soils.

The extensive coverage and quite high resolution of space photographs makes it possible to obtain much information on the structural-geomorphological characteristics of the analyzed natural regions and their relationships to the soil cover of the corresponding geotextures and morphostructures of the earth's surface.

Vegetation, Agricultural Activity and Their Indication Role in the Study of Soils

In the interpretation of soils it must be remembered that the soil cover can show up on aerial and space photographs directly in the case of plowing of a territory (fields not covered by cultivated vegetation) and indirectly through the image of forest, natural grassy and cultivated (agricultural crops) vegetation.

Different plant associations are discriminated on photographs on the basis of image tone and pattern (texture).

As pointed out by Viktorov (1973), Vinogradov (1966), Simakova (1959), Tolchel'nikov (1974), the image tone of vegetation is influenced to a considerable degree by spectral brightness, composition of the vegetation and the projective coverage of the soil surface. The same as the image tone of the soil surface, to a considerable degree it varies under the influence of photographic and processing conditions. The pattern of the photoimage of vegetation is considerably more stable and universal.

Considerable plains areas of the steppe zone have now been plowed. In the European USSR steppe vegetation has been preserved for the most part along ravines, on the slopes near ravines and on river floodplains. Against the image background of chernozems and chestnut soils it is easy to interpret meadow-chernozem soils associated with longitudinal troughs and ravines. On photographs they have linear-dendritic forms of a gray and dark gray tone characteristic for the image of meadow and meadow-steppe vegetation. The photographs show that the reliability of their interpretation is different in dependence on season and type of used film. On the basis of the different image of meadow and swamp vegetation we clearly interpreted the soil cover of floodplains of different genesis on aerial photographs.

In the Asiatic part of the steppe zone steppe vegetation still occupies considerable expanses in the territory of Kazakhstan, Altayskiy Kray and especially Mongolia.

Now we will examine the characteristics of the photoimage of a number of plant associations and their correlations with the soil cover in the territory of the steppe part of Kazakhstan and Mongolia. In the northern regions of Kazakhstan there are mixed grass-feathergrass-sheep's fescue groupings on ordinary and southern chernozems (Vinogradov, 1966; Preobrazhenskiy, 1959; Tolchel'nikov, 1966). On aerial photographs they show up as a pattern of small spots of light gray, gray and dark gray tones. The light gray spots correspond to sectors with a predominance of tall grasses and dark gray tones correspond to areas with a predominance of mixed grasses. There is a rather widespread occurrence of mixed grass-sheep's fescue-feathergrass associations on dark chestnut soils of a light mechanical composition which on the photographs have a gray or dark gray photoimage tone with a uniform or moiré pattern. A dark-gray tone, frequently of a dendritic form, corresponds to a quack-grass-brome grass association on meadow-chestnut soils. ~~Mixed-grass~~ - wormwood plant groupings with the participation of petrophytes are formed along the crests of ridges on thin gravelly chestnut soils. On aerial photographs they show up in a light-gray tone of a curving-striated texture.

Along the margins of swales or in troughs well-expressed in the relief there are meadow grass-quack grass meadows on meadow solonetz-like soils.

The central part of the swales is occupied by mixed-grass - sedge - swamp vegetation. The photoimage tone is mottled, from light gray to dark gray; the texture is one of small spots. Overgrowths of reeds also show up in a bright-light (sectors with dry reeds) to a dark gray tone (in the case of a thin stand of the reed overgrowths, when the water can be seen through the reeds). The texture is circular-spotty. In depressions a dark gray tone corresponds to salt-loving groupings on moist solonchaks. With the dessication of the surface crust with salts they show up in an almost white tone.

On the water divides dots of an almost white tone correspond to excavated soils at the mouth of marmot burrows with thin black wormwood-camphor groupings on them. Old abandoned mouths of marmot holes, covered by curtains of quack grass, show up as small dots of a black tone.

The investigations which we made over a long-term period in the territory of the steppe zone of Mongolia (Table 18) indicated that a light gray and gray tone of a spotty pattern with low-contrast boundaries of the areas on medium-scale aerial photographs correspond to a wormwood-bistort-feathergrass association with caragana, formed on chestnut sandy loam soils. With respect to relief conditions, they occupy slightly undulating sectors of high plains, slopes of ridges and intermont depressions. The peaks of ridges and sectors of steep slopes are occupied by wormwood-bistort-feathergrass vegetation with the participation of petrophytes. Thin chestnut gravelly soils have formed beneath this vegetation and on the photographs have a light gray photoimage tone.

Chestnut soils with high effervescence have developed on alluvial fans and on the lower parts of the slopes of intermont basins beneath wormwood-bistort-feathergrass associations of the dry steppe with the participation of caragana. Due to the microrelief they show up in a black tone of striated pattern on the photographs.

In troughs on ridged plains and in intermont basins meadow-chestnut and meadow-chestnut steppized soils have formed under mixed grass-grass associations, sometimes with the participation of Lasiagrostis. On the photographs they are interpreted from the linear-dendritic form of units of a gray and dark gray tone, having contrasting boundaries. The deepest sectors of the longitudinal troughs and the peripheral parts of the swales were occupied by meadow solonchak-like soils with mixed meadow grasses (Lasiagrostis, iris, etc.). These soil units have sharply contrasting boundaries, a dark gray tone and a rounded-linear image form. An almost white tone is characteristic of meadow solonchaks, dessicated from the surface, covered by thin solonchak vegetation (seepweed, Russian thistle, etc.). Poorly consolidated sands show up in an almost white tone of a cellular-ridged pattern. Milk vetch, wildrye and other psammophytes are conspicuous.

A number of alluvial soils characteristic for different geomorphological sectors of the floodplain were successfully interpreted also in the territory of the floodplain of the steppe Tola River on the basis of the different photoimage of vegetation on aerial photographs.

A light gray tone of a crested-meandering pattern on the photographs corresponded to the part of the floodplain along the channel with a thin mixed-grass-grass vegetation developed on alluvial (floodplain) meadow poorly developed sandy soils. A gray tone of a meandering pattern with contrasting boundaries corresponds to the image of grass-mixed grass-meadow vegetation growing on flat sectors in the central part of a floodplain with alluvial (floodplain) meadow soils. A dark gray tone of a fanlike-meandering pattern corresponded to sectors of overgrown ox-box lakes and different channels in the territory of the central floodplain under a mixed-grass vegetation with the participation of swampy species and reeds. The soil cover here is represented by alluvial (floodplain) meadow soils. Finally, an almost white tone of a rounded-spotty form corresponds to still another component of the soil-vegetation cover of the floodplain. In individual sectors of the part of the floodplain near the terrace it is represented by alluvial solonchak-like soils and solonchaks which have developed here under meadow-solonchak vegetation.

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Thus, this analysis of the photoimage of natural grassy vegetation and the determination of its correlations with soils indicated the possibility of a successful interpretation of the soil cover from aerial photographs on the basis of one of the principal indirect criteria.

Most of the lands in the steppe zone are plowed and sown in grain and industrial crops. According to N. N. Rozov (1968), in the territory of the steppe zone, having 186 million hectares of arable lands, gardens and orchards account for 50%, hayfields, pastures and other grazing land -- 35.1%, forests and scrub -- 0.6%, not used in agriculture -- 14.3%.

A specific characteristic of interpretation of soils in the steppe zone from aerial and space materials is that on photographs from the summer survey season this interpretation is accomplished through cultivated agricultural vegetation. In fields covered by sprouts the soil surface is to a different degree concealed from direct representation on aerial photographs. Our investigations indicated that only dense and fully grown crops completely conceal the soil surface. Low sprouts, young or thin plantings cannot completely conceal differences in color and image pattern and other direct indicators of soil nonuniformity of fields. Grain crops in the phases from sprouting to leaf tube formation exert little influence on the photoimage of soils. With the leaf tube formation phase grain crops receive good vegetative development, virtually completely covering the soil surface and on black-and-white photographs show up in a uniform dark gray tone (Vinogradov, 1966).

The image on aerial photographs of fields with high crops and good vegetative development of plants is completely dependent on the type of agricultural crops and their stage of development (Figures 14 and 14a). Using summer aerial and space photographs with the greatest completeness it is possible to determine the distribution of agricultural crops and their state in dependence on soil, climatic and agroengineering conditions. Moreover, there are many cases when cultivated vegetation emphasizes the differences in the image of different soils.

It can be seen from our comparisons of aerial photographs with the direct image of arable land and cultivated vegetation that from the image of plantings of rye in the stage of milky-gold ripeness it is easy to see the difference between dark gray forest soils and chernozems. Using the photographic image of grain crops it is easy to interpret shallow erosional troughs, sectors with sandy and sandy loam soils; it is easy to make out waste lands and sectors with weedy vegetation.

In the territory of the "Gigant" grain sovkhoz in Rostovskaya Oblast an aerial survey of agricultural crops was carried out using black-and-white film at three times: first -- when the grain fields were in the tillering or leaf tube extension phases; second -- in the earing or flowering phases; third -- in the phases of milky or gold ripeness. As the basic criterion we did not use the image tone (which is unstable), but the relationship of tones. Spectrozonal photographs had the greatest information content. Using the photographs it was possible to determine the different weediness of sown areas and also ascertain sectors with thin plantings and beating-down of grain crops (these are shown in a lighter tone). Fields of winter wheat and barley cannot be discriminated from one another. Cornfields had a dotted structure of the pattern (Mokiyevskiy, Ogorodnikov, 1966).

Each agricultural crop in the course of its development attains an optimum stage in which it can be identified on the photographs among other crops. An analysis of panchromatic photographs of a number of agricultural regions in the United States indicated that corn, soy beans, wheat, oats, barley and grasses can be differentiated on aerial photographs on the basis of their coloration and structure. Photographs taken in the second half of July were optimum.

In the identification of agricultural crops an important role should be played by data on their spectral reflection (Deyneko, Yelesin, 1972; Yelesin, et al., 1977; Nekhoroshev, et al., 1972; Rachkulik, Sitnikova, 1976; Tolchel'nikov, 1974; Tolchel'nikov, Khazanova, 1973).

Thus, a study of the photoimage characteristics of natural and cultivated vegetation on photographs has both independent importance for study of diseases of agricultural crops and determining their yield and for ascertaining correlations with the nature of the soil cover

Specific characteristics of the indication role of vegetation and agricultural activity in the interpretation of soils on space photographs. New aspects of study of the vegetation cover and man's agricultural activity and their indication role for determining soils arose with the use of space photographs in soil science and agriculture. B. V. Vinogradov, K. Ya. Kondrat'yev (1971), Ye. A. Vostokova (1977), Ye. V. Glushko (1976), L. F. Yanvareva, Ye. M. Nikolayevskaya (1974), N. G. Kharin (1969), R. N. Colwell (1971), MacDonald, Kristof (1971) and other researchers note a quite high detail in the identification of vegetation, good reflection of agricultural fields and the possibility of determining crops and the condition of fields. This makes possible successful interpretation and mapping of land use and an indirect determination of the character of the soil cover from space photographs.

Now we will give an analysis (Vinogradov, 1976) of a space photograph taken in June 1970 during the flight of the "Soyuz-9" over the territory of the Sal'skaya dry steppe with chestnut soils. Fields 16 hectares in area can be identified. Eroded soils are interpreted at the heads of ravines in cultivated lands, appearing as bands of a lighter tone. Narrow discontinuous bands of a dark gray tone correspond to ravines with tree-scrub and meadow vegetation. Sectors of a light gray uniform tone, situated along the slopes of ravines, represent grazing land, representing pasture occupying here about 38% of the territory.

In the flight of the "Apollo-9" spaceship use was made of multispectral photographs of the earth's surface for the automatic interpretation of agricultural fields. An analysis of photographs made in the United States with use of an electronic computer made possible an automatic determination of barley fields with an accuracy to 75%, sugarbeets — 59%, alfalfa — 27%. Sectors of bare fallow and saline soils were clearly interpreted on the photographs. Cabbage, lettuce and other vegetable crops were very difficult to interpret.

Using a small-scale TV image of the earth's surface obtained from the "Nimbus-1" artificial earth satellite it was possible to ascertain the affinity of soils to definite vegetation formations, relief forms and rocks. However, it is not always possible to identify soil areas on these photographs. For example, in the territory of the Paris basin (France) brown podzolized soils were identified 60% because of differences in vegetation, brown calcareous soils — 40%, rendzinas — 70%, alluvial soils — 80% (Vinogradov, Kondrat'yev, 1971).

Using space photographs taken from the "Salyut-1" orbital station for the territory of the steppe zone of Kazakhstan and Altayskiy Kray and having a better interpretability than TV images, V. I. Kravtsova (1974) and I. V. Kopyl, et al. (1975) demonstrated the indicator role of vegetation and fields of agricultural crops for the purposes of soil interpretation. In fields occupied by perennial grasses and in sectors with artificial scuffling the soil cover to all intents and purposes cannot be seen. It is difficult to see soil differences in fields of fallow. Meadow variancs of soils forming in longitudinal troughs are readily interpreted through differences in the gray tone of fields occupied by wheat. Differences in overmoistening and salinization of soils were successfully determined through the photoimages of meadow-swampy moisture-loving and halophytic vegetation, frequently associated with depressions around lakes and old lake depressions. Steppe solonetz soils, associated with outcropping of Neogene clays at the surface, were discriminated in cultivated lands through plantings of grain crops on the basis of the light gray tone of a spotty pattern

On a space photograph taken from the "Salyut-1" it is also possible to make a direct interpretation of such land use units as forests, cultivated lands, extensive areas in a natural state and unused lands. On the basis of direct and indirect criteria it is also possible to determine erosion, salinity and swampiness of the soil cover.

On space photographs in the steppe zone and in the area transitional to the mountain-forest zone the degree of identification of different types of vegetation is different. It is easy to interpret areas of forest vegetation, but the species separation of forests is difficult. In addition, it is difficult to interpret forests having a patchy character. In ravines it is hard to distinguish them from meadow vegetation, which shows up in a similar dark gray tone. Through forest vegetation it is very easy to interpret sectors of strip pine forest with pine-covered, partially deflatable sands. A mountain forest zone with mountain gray and dark gray forest soils can be seen clearly on the photographs. Alluvial soils of river valleys can be interpreted from the photoimage of intermont basins, partially plowed or occupied by steppe vegetation.

Steppe vegetation has different interpretability on space photographs. Zonal types of steppe vegetation cannot be differentiated. In addition, it is easy to discriminate halophytic groupings on saline soils, psammophytic steppes of sandy areas, petrophytic steppes in regions of conical hills and foothills. The characteristics of change in image structure of light tones on a space photograph make it possible to discriminate on the photographs halophytic groupings of solonchaks, solonchak-like meadow soils, meadow and steppe solonetz soils. From the dense, almost black phototone it is easy to interpret swamp vegetation and vegetative groupings with an increased moisture content.

Thus, the cited examples show different possibilities of interpretation of vegetation and agricultural fields and the soils determined from them on the basis of use of photographic, television-frame and scanner space photographs.

Photographic and multizonal scanner photographs have the best possibilities with respect to indirect interpretation of soils.

Chapter 4

INFLUENCE OF CHANGES IN NATURAL CONDITIONS ON PHOTOIMAGE OF AERIAL AND SPACE PHOTOGRAPHS

The effectiveness of use of materials from an aerospace survey for the purpose of interpretation and study of the soil cover and the condition of agricultural crops is dependent to a considerable degree on the time when the survey is made. As indicated by our investigations and our discussion of these matters with agricultural specialists in the United States (A. Park, M. Holter and R. Arnold) during a Soviet-American meeting at the Space Research Institute USSR Academy of Sciences, for soils-agricultural purposes it is promising to carry out a survey not less than four-six times a year.

Depending on the nature of the problems to be solved, for example, for studying the dynamics of snow melting in the spring and the development of the processes of sheet and linear water erosion, it is desirable that in the early spring a survey be made each three to five days. A survey in this first early spring period prior to the dessication of the upper soil layer can be used successfully in a study of soil moisture content. A second spring period, when the soil surface has dried out, the period of maximum plowing of the fields, is the most promising time for study of the soil cover because at this time the soil cover shows up directly on the photographs.

R. Evans (1975) points out that an aerial survey of cultivated areas for soil purposes should best be carried out in the spring when the land is free of crops.

Two subsequent summer periods (one the stem extension stage for grains and the formation of fruits of agricultural crops and a second stage, the maturing of plants) are most effective for ascertaining the development of agricultural crops in dependence on soil fertility and the application of fertilizers, irrigation, and in the last analysis, for determining their crop yield.

The next autumn period for an aerospace survey can be used in determining the moisture content, autumn moisture reserves in the soils, by SHF methods at the time of mass sowing of winter crops, study of their condition and development.

In steppe and dry steppe regions interesting observations of the distribution of the snow cover over the soil surface can be carried out using photographs of a winter survey.

The problems involved in the influence of changes in natural conditions on the photoimage of aerial photographs have been considered in a whole series of studies related to the interpretation of aerial photographs (Bogomolov, 1976; Gol'dman, 1960; Grigor'yev, Simakova, 1971; Vinogradov, 1966; Simakova, 1959; Tolchel'nikov, 1974). On the basis of investigations the optimum time is established for carrying out the aerial survey. On the basis of an analysis of diurnal changes in illumination of the earth's surface Yu. S. Tolchel'nikov (1974) points out that in forest regions an aerial survey must be carried out when the sun has a high altitude (40-60°), in steppe regions -- 60 and 20-30°; in desert regions -- 15-30°. It is undesirable that an aerial survey be made when solar altitudes are less than 15-20°. Data are available on the influence of the time of a survey on the interpretability of meliorated soils in the desert zone (Kuznetsov, 1965; Mazikov, 1976; Pankova, Mazikov, 1976).

Weather conditions and their changes exert an influence on atmospheric transparency and illumination of the earth's surface. Therefore, in making an aerial survey an allowance is made for the presence of air and dust haze. The latter occurs particularly extensively in the desert zone at near-midday hours. Other atmospheric phenomena associated with weather conditions, especially in the case of small-scale and space surveys, are the presence and type of cloud cover. Clouds show up as spots and bands of an almost white tone, with blurred edges, and the shadows from them show up as dark spots.

A study of the influence of weather conditions on the nature of the photoimage of soils is of special interest when using space photographs because they can be used in direct registry of extensive moist sectors of soils after a rain, the territories subject to drying winds, dust storms and other weather phenomena.

Next we will cite the long-term and seasonal changes in the photoimage of the soil cover and agricultural crops on photographs. In the example of individual natural regions in the steppe zone we will examine the characteristics of the photoimage of soils and fields of agricultural crops on aerial and space photographs obtained for the same season in different years and different seasons in one year.

Investigation of Changes in the Photoimage of Soils and Agricultural Lands Using Materials from Different Survey Years

For the effective use of aerial and space photographs and interpretation of the soil cover from them it is of great importance to choose a definite season for different survey years and the stability of the photoimage of the soil cover is important in this choice. We will examine a series of photographs taken in different years.

On the first two spring aerial photographs obtained with a gap of seven years for one and the same territory we studied the type of soil cover of the steppe Syrtovoye Zavol'zhe, characteristic for flat-topped watersheds made up of brown watershed clays. These soils are characterized by a uniform pulverized mechanical composition with a rather dense fine-pored structure. They have a brown color, have a calcareous makeup and usually contain gypsum in small quantities. Southern chernozems of moderate thickness are formed on them with individual spots of excavated chernozems (at the mouth of marmot burrows). Southern chernozems are interpreted from their position on watersheds, which can be seen clearly in a stereoscopic examination of relief on aerial photographs. Due to the heavy mechanical composition and considerable humus content (4.7-5.5%) the image tone of the soil surface is dark gray, whereas the tone of the freshly plowed sectors is dark. Against the general dark gray background it is easy to see the light-colored dots of hillocks at the mouths of marmot burrows, excavated chernozems. Poorly and moderately eroded chernozems have developed on the watershed slopes. These soils are characterized by a decrease in the humus content in the upper horizon and the appearance of rills. On aerial photographs these soils stand out clearly from the mottled ribbed image pattern of the rills and runoff troughs on the slope and an image tone which is lighter due to the washing away of humus and calcareousness. The image of sectors of moderately and strongly eroded southern chernozems has a bright-light tone.

On the aerial photographs it is easy to discriminate depressions below the watersheds and runoff troughs on the slopes of watersheds with meadow-chernozem soils forming on them. Due to the increased moisture content, heavy mechanical composition, high humus content (6-7%) and thick humus horizon these soils show up on the aerial photographs in the darkest tone of a uniform pattern. Depressions beneath the watershed and troughs can be seen clearly in a stereoscopic examination of the relief with the use of stereoscopic instruments.

The depression below the waterdivide adjoins the sector of the second terrace above the floodplain of a steppe river. The surface of the terrace is level, complicated by flat-bottomed troughs. Here terrace southern chernozems of moderate and small thickness, "excavated" chernozems and meadow chernozems are formed. In the morphological structure of the profile and physicochemical properties terrace southern chernozems have many features in common with southern watershed chernozems. On aerial photographs they have a similar tone and pattern of the photoimage. A good distinguishing characteristic of these soils is their position on the terrace, which is seen clearly in a stereoscopic study of aerial photographs.

A comparison of the photoimage of the soil cover on these two photographs, taken over a series of years under uniform natural and technical survey conditions, demonstrated that it is similar.

On two other aerial photographs, taken at a seven-year interval, a study was made of the type of soil cover characteristic for the watersheds of the Syrtovoye Zavolzh'ye, consisting of soils of light mechanical composition. It can be seen from an analysis of the photographs that as a result of excessive plowing deflated soil areas have been formed in cultivated lands, having a wedge shape with a light gray tone. It is obvious that in order to preserve these soils there must be a temporary regrassing of the lands subject to wind erosion.

The next aerial photographs obtained for different survey years reveal the dynamics of agricultural and melioration activity in an area. On the first two photographs of a sector of the high floodplain of the Dnestr River with alluvial calcareous clayey loam and light clayey loam sandy soils there is a distinct difference in the nature of the agricultural use of soils. A photograph taken in a survey in 1959 shows the beginning of land use by gardens. On a photograph taken in a 1967 survey the entire territory of the floodplain was in gardens; it is easy to interpret sectors of old and young gardens and a leveled segmental image pattern of the soil cover.

Another two aerial photographs show what a substantial change there has been in the image of swampy soils after melioration. On a photograph from the survey of 1959 the image of alluvial swampy soils has a very mottled rounded-spotty pattern of different tone (from almost white to dark gray), related to the different vegetative development of swampy vegetation: rushes, cattails, reeds and other species. After melioration the photoimage of swampy soils acquires a relatively uniform dark gray tone with a conspicuous network of melioration canals.

Thus, in an analysis of long-term changes in the photoimage of the soil cover it is necessary to bear in mind the following three principal variants.

1. A stable character of the photoimage of soils when upon the elapsing of ten or more years we have a similar image of the soil cover for the spring season.

2. A modified (in part) nature of the photoimage of the soil cover, related, on the one hand, to erosion, and on the other hand, to man's agricultural activity.

3. A considerably modified nature of the photoimage of soils on photographs of different survey years, related to radical meliorated exploitation of the soil cover. These changes are interpreted primarily from the nature of the photoimage pattern of soils.

Investigation of Changes in Photoimage of Soils and Agricultural Lands Using Materials from Different Survey Seasons

A study of seasonal changes in the soil cover and agricultural crops from aerial and space photographs is an important task in both theoretical and practical respects for the interpretation and successful use of photographs.

At the present time in our country and abroad serious investigations are being carried out for study of the influence of seasonal changes on the interpretability of soils and agricultural crops.

Now we will examine the possibility of interpretation of soils and agricultural crops in a steppe zone, exploited agriculturally to a considerable degree, in dependence on different survey seasons.

In spring (April, May), after disappearance of the snow, the soils on the water divides dry up quite rapidly from the surface, except for circular and longitudinal depressions, the "amphitheaters" of ravines, lower parts of slopes, depressions below water divides and watersheds.

In spring our determinations of the surface moisture content of soils at the time when an aerial survey (14 May 1970) was carried out in the territory of the Syrtovoye Zavolzh'ye demonstrated the following (Table 19).

Such soil indices as humus, calcareousness and moisture content are of considerable importance for the successful interpretation of southern chernozems, southern weakly eroded chernozems, southern moderately and strongly eroded chernozems and meadow-chernozem soils.

The data in Table 19 show that with an increase in the degree of erodability of southern chernozems the humus content decreases from 4.7 to 2.2%; there is a sharp (from 2.62 to 24.52% $CaCO_3$) increase in the calcareousness and a corresponding decrease in soil moisture content. On the photograph there is a change in the photoimage of the soil cover from dark gray to a light tone. The greatest content of humus (5.5%) and moisture in the soil (24.3% in the layer 0-5 cm) and the minimum presence of carbonates (0.91% $CaCO_3$) are observed in meadow-chernozem soil, for this reason on the photograph having an almost black photoimage tone. The detection of these soils by means of the "Kvantimet-720" indicated that they can be determined successfully from the quantitative indices of the gray tone scale.

On the basis of an analysis of the photoimage of soils on early spring photographs (April) for an experimental sector of the steppe zone, when snow still lies in the ravines in places, we compiled a soil map (Figures 15 and 15a) most reliably and precisely and it was possible to discriminate three stages of soil moistening: dry, moistened, moist. An almost black tone (for plowed chernozems) or dark gray (for stubble) are characteristic of moist soil sectors. Moistened soil areas have a dark and dark gray tone. Typical chernozems dried from the surface have a dark gray tone; sectors of stubble have a gray, locally a light gray tone. Meadow-chernozem soils, due to an increased moisture content, show up in an almost black tone. An almost black tone is characteristic of sectors of freshly plowed and harrowed fields and agricultural fields with plantings of winter crops which have survived the winter well. Fields of spring and industrial crops begin to exert an influence on the photoimage tone 2 or 3 weeks after sprouting.

Pastures on the slopes of ravines and covered with a grassy vegetation show up in a light gray tone due to its poor development in the early spring (Fig. 15).

During the spring period virgin land vegetation only begins to fluorish and therefore on the photoimage of the photographs the dry steppe matting of the preceding year and the differences in moistening of the surface in dependence on micro- and mesorelief exert a substantial influence. In general, virginland sectors with typical chernozems show up in a gray or light gray tone. Against this background it is easy to interpret (from the dark gray tone) troughs and ravines with meadow-chernozem soils. Small light gray circular spots clearly represent the driest microhillocks with excavated calcareous chernozems (at the mouths of marmot burrows). On a spring photograph of a virgin sector of the Kursk polygon it was also possible to see clearly, from the lighter image tone, the image of a soil area with a predominance of excavated calcareous chernozems against a background of typical chernozems with ordinary and reduced effervescence.

The spring period, due to the detailed and direct representation of the soil surface on photographs (until agricultural crops begin to mask the soils), is the best time for aerial and space surveys of the soil cover and the study of different soil moisture content from photographs.

In the summer the soil surface (except for fallow fields) is covered by dense plantings of agricultural crops. This is the best time for the study of the type of agricultural crops, their condition, nature of weediness and possible determination and prediction of the yield of crops from aerospace materials.

Our investigations indicated that for these purposes it is best to use spectrozonal photographs. Figures 16 and 17 (see insert) show not only a clear separation of different types of agricultural crops, but also sectors and areas with different development and condition of the sown crops. However, there is no differentiation of the soil cover which would be clearly visible on a spring photograph.

Accordingly, if for the territory to be analyzed there are no photographs from a spring survey, fields of bare fallow are of great importance in characterizing the soil cover, its structure and soil characteristics.
In a soil field investigation on the basis of summer photographs a more detailed analysis is made of adjacent fields and these serve as key sectors in the study and mapping of the soil cover of surrounding territories.

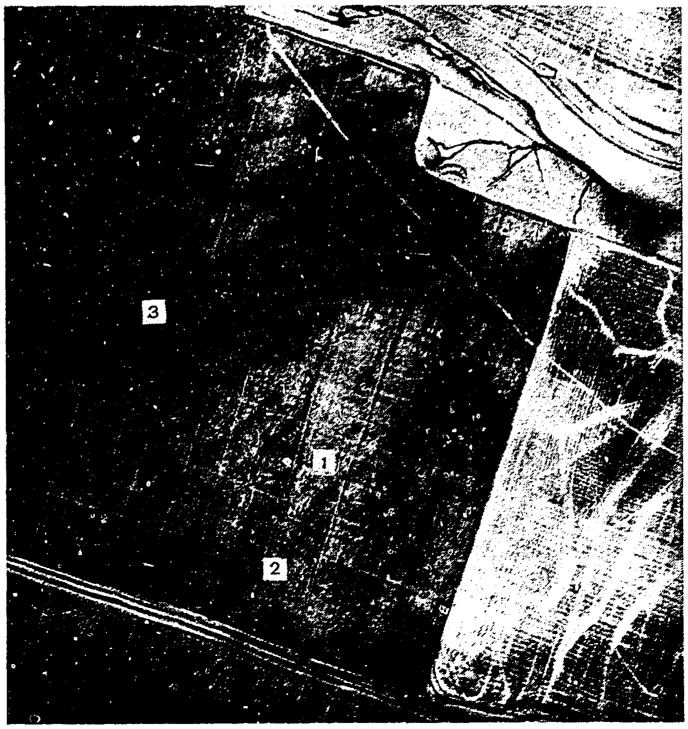

Fig. 15. Aerial photograph of territory of slope of experimental sector of steppe zone near ravine. The survey was made in spring (April). Soil surface: 1) dry; 2) moistened; 3) moist

Virginland mixed-grass vegetation was well developed in summer. On black and-white aerial photographs it shows up in a relatively uniform gray and dark gray tone. The differentiation of soil conditions is considerably better when using spectrozonal photographs (from orange and orange-greenish colors). In the dry steppe zone the vegetation usually burns up and has a poor differentiation.

In the autumn a considerable number of fields are again plowed and on aerospace photographs there is direct representation of the soil cover. The early autumn period of harvesting of agricultural crops is reflected in the photoimage of photographs. It was established that it is exceedingly difficult or virtually impossible to interpret the soil cover of chernozems (Fig. 17).

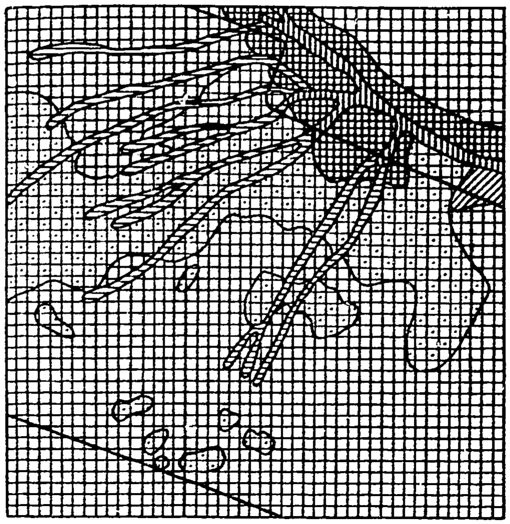

Fig. 15a. Soil map compiled from aerial photograph of territory of experimental sector of steppe zone near ravine. Soils: 1) typical thick chernozem with ordinary effervescence and typical thick chernozem with reduced effervescence on loessial clayey loam; 2) typical thick chernozem with reduced effervescence on loessial clayey loam; 3) typical chernozem (weakly eroded calcareous soil at mouth of marmot burrows) and typical chernozem with reduced effervescence on loessial clayey loam; 4) typical chernozem (moderately eroded calcareous soil at mouth of marmot burrows) and typical chernozem with reduced effervescence on loessial clayey loam; 5) leached meadow-chernozem soil on deluvial clayey loam; 6) leached meadow-chernozem and alluvial meadow-chernozem soil on deluvial clayey loam.

On autumn photographs we established the presence of sectors and fields from which crops had not been harvested on time. The following year in these sectors there is a poorer development of plants and a decrease in the yield of agricultural crops. In places where in autumn there was a delay in the harvesting of potatoes in the following year on the photograph (summer survey season) this sector is clearly interpreted on the basis of tone and color. This change in tonality is related to the poorer development of agricultural crops.

Virginland vegetation, on both black-and-white and on spectrozonal aerial photographs for the autumn survey period, is shown more differentially than on summer photographs. The same as on spring photographs, small round spots, but of a dark gray tone, correspond to microhillocks with excavated calcareous chernozems at the mouth of marmot burrows. Amidst the virginland steppe it is easy to interpret soil areas with a predominance of calcareous excavated chernozems amidst typical chernozems with ordinary and reduced effervescence. Drainage troughs and ravines with meadow-chernozem soils can be seen quite clearly.

In the dry steppe zone the most significant seasonal changes in the soil cover are characteristic for solonchaks and solonchak-like complexes. In spring and in late autumn in a moist state they are represented on the photographs by an almost black or dark gray tone. In summer with dessication the solonchaks are covered with a salt crust and on the photographs have an almost white tone.

We will examine the influence of seasonal conditions on the photoimage of the soil cover and agricultural crops on space photographs in the example of the steppe zone. In the analysis we used black-and-white photographs of an experimental sector of the steppe zone obtained on 10 May and 8 August 1975 in the spectral zone 0.7-0.8 μm, and also 0.6-0.7 and 0.8-1.1 μm. In the spring and autumn periods surface field investigations were made in this territory for the purpose of studying the characteristics of the soil cover and the distribution of agricultural crops.

A study of the characteristics of the photoimage of space photographs and their comparison with data from surface investigations indicated the following.

During spring, from a space photograph taken in the red and near-IR spectral zones (0.7-0.8 μm) from the dark gray tone it is easy to interpret bare fallow and fields in which agricultural crops have been sown (sugar-beets, corn, buckwheat, potatoes) (Table 20). An analysis of these fields makes it possible to interpret the distribution here of typical chernozems and meadow-chernozem soils on the basis of the homogeneous structure and the dark gray tone of the surface photoimage. In those cases when meadow-chernozem soils have been plowed they are interpreted on a space photograph from the uniform, almost black tone characteristic for typical chernozems having a heavy mechanical composition and 6-7% humus.

If meadow-chernozem soils are not plowed, they are reliably interpreted from the almost white image tone of the mixed-grass vegetation of longitudinal troughs and ravines.

On a space photograph of the spring survey period, on the basis of the light gray, and locally almost white tone of the photoimage, there is reliable interpretation of gray and dark gray forest soils with the participation of eroded soils and poorly consolidated sands. The photograph clearly shows the different character of erosional dissection of the territory. For example, the territory of an experimental sector of the steppe zone adjacent to the left bank of the Seym River is characterized by weak dissection (about 20% of the land is accounted for by gullies and ravines). There is a marked increase in the dissection of the territory by a gully-ravine network into local watersheds and the common watershed of the Central Russian Highland between the tributaries of the rivers of the Don and

Table 19

Content of Humus, Carbonates, Spring Moisture Content of Soils of Syrtovoye Zavolzh'ye and Photoimage Tone

Soil	Глубина, см 1	Гумус 2	CaCO$_3$	% Moisture content				Photoimage tone		3 Разность уровней серого тона по отношению к черноземy южному среднемощному
		%		n	M	$3m$	σ	visually	4 уровень серого тона	
Moderately thick southern chernozem on brown watershed clay	0—1	4,7	2,62	12	7,2	1,2	1,3	Gray	38—42	—
	0—5	—	—	12	19,8	2,4	2,7			
	5—10	4,8	2,95	12	30,7	2,4	2,7			
	10—20	—	—	12	31,6	1,2	1,5			
	20—30	4,8	2,95	12	30,8	1,8	1,9			
Weakly eroded southern chernozem (watershed slope)	0—1	3,6	6,81	14	4,8	0,6	0,6	Light gray	43—48	5
	0—5	—	—	14	14,8	1,8	1,9			
	5—10	3,7	6,81	14	27,7	2,3	2,4			
	10—20	—	—	14	29,4	1,5	1,6			
	20—30	3,6	7,03	14	29,7	1,5	1,7			
Moderately and strongly eroded southern chernozem (steep watershed slope)	0—1	2,2	24,52	5	2,2	0,6	0,5	Almost white	49—57	13
	0—5	—	—	5	10,0	2,1	1,6			
	5—10	2,2	23,61	5	20,7	3,9	2,8			
	10—20	—	—	5	22,4	4,2	3,0			
	20—30	2,4	34,95	5	21,7	5,7	4,2			
Meadow-chernozem soil on rock waste glayey loam (longitudinal troughs on watershed slope)	0—1	5,5	0,91	9	13,0	2,4	2,4	Darkish gray	33—37	—5
	0—5	—	—	9	24,3	4,5	4,6			
	5—10	5,5	0,91	9	35,3	2,4	2,4			
	10—20	—	—	9	36,7	1,5	1,6			
	20—30	5,5	0,68	9	36,1	2,1	2,0			

KEY:

1. Depth, cm
2. Humus
3. Difference in levels of gray tone relative to medium-thick chernozem
4. Gray tone level

Table 20

Data from Visual-Instrumental Interpretation of Agricultural Crops in Experimental Sector of Steppe Zone from Space Photographs Taken from ERTS-1. Typical Chernozems and Meadow-Chernozem Soils. Time of Survey 10 May 1975

Agricultural crops and their condition	Survey spectral zone					
	0,7—0,8 мкм (μm)			0,8—1,1 мкм (μm)		
	tone	уровень серого тона 1	разность уровней серого тона по отношению к черному пару 2	tone	уровень серого тона 1	разность уровней серого тона по отношению к черному пару 2
Winter wheat	Light gray	40—50	17	Light	45—52	22
Spring wheat with	Gray	35—45	12	Light gray	40—47	17
undersowing of clover (sown 15 April)	»	36—45	13	»	40—47	17
Barley (planted 12 April)	»	38—42	12	»	40—47	17
Vetch-oats (sown 4-8 April)						
Peas (planted 6 April)	Darkish gray	28—32	2	Darkish gray	31—36	7
Buckwheat (sown 7-11 May)	Dark gray	25—30	0	Dark gray	23—30	0
Corn (planted 8-10 May)	Same	25—30	0	»	23—30	0
Sugar beets (planted 21-24 April)	» »	25—30	0	»	23—30	0
Potatoes (planted 10 May)	» »	25—30	0	»	23—30	0
Bare fallow	» »	25—30	—	»	23—30	—
Alfalfa (2d and 3d years)	Almost white	50—60	27	Almost white	52—60	29
Perennial grasses (sweet-clover, clover, timothy)	» »	50—60	27	» »	52—60	29

KEY:

1. Level of gray tone
2. Difference in level of gray tone relative to bare fallow

Table 21

Data from Visual-Instrumental Interpretation of Agricultural Crops in Experimental Sector of Steppe Zone from Space Photographs Taken from ERTS-II. Typical Chernozems and Meadow-Chernozem Soils (Survey Time 8 August 1975)

Agricultural crops and their state	Survey spectral zone					
	0,7—0,8 мкм (m)			0,6—0,7 мкм (m)		
	tone	уровень серого тона 1	разность уровней серого тона по отношению к полупару 2	tone	уровень серого тона 1	разность уровней серого тона по отношению к полупару 2
1 Полупар (сев озимых 20—25 августа)	7 Темно-серый	24—30	—	12 Серый—темновато-серый	30—40	—
2 Стерня зерновых культур	8 Светлый	45—55	23	13 Светлый—светло-серый	42—50	11
3 Кукуруза (уборка 15 августа)	9 Почти белый	50—55	25	7 Темно-серый	25—32	6
4 Кукуруза (стерня)	10 Серый	35—45	13	8 Светлый	46—50	13
5 Сахарная свекла (уборка 12—25 сентября)	11 Белый	55—61	31	7 Темно-серый	25—32	6
6 Люцерна (2-го и 3-го года)	9 Почти белый	52—58	28	14 Темный	19—23	14

KEY:

1) Bastard fallow (sowing of winter crops 20-25 August)
2) Stubble of grain crops
3) Corn (harvest of 15 August)
4) Corn (stubble)
5) Sugarbeets (harvest of 12-25 September)
6) Alfalfa (2d and 3d year)
7) Dark gray
8) Light
9) Almost white
10) Gray
11) White
12) Gray-darkish gray
13) Light-light gray
14) Dark

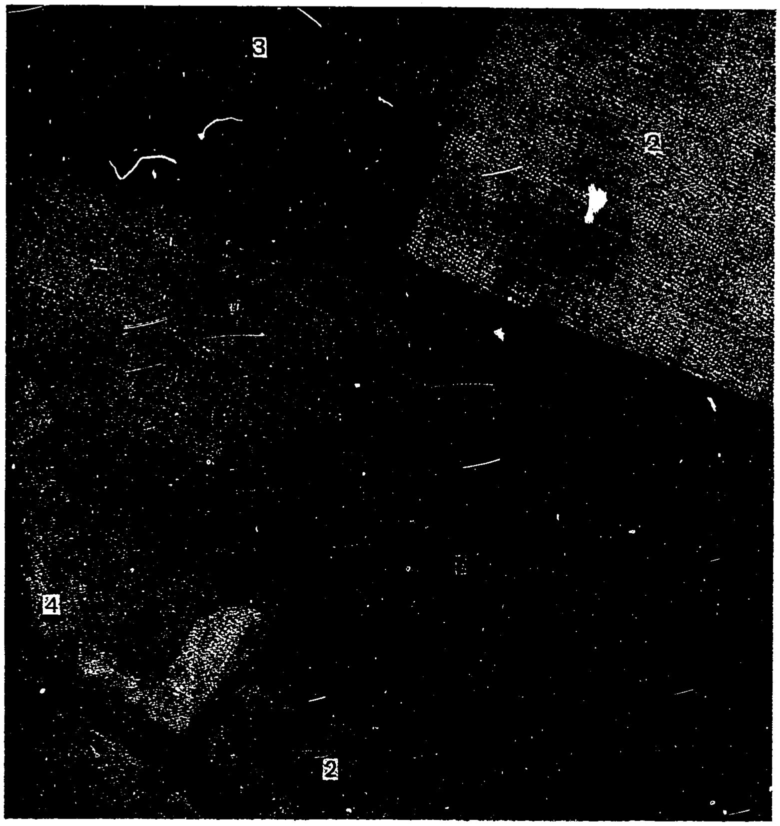

Fig. 16. Spectrozonal aerial photograph of territory of slope along ravine in experimental sector of steppe zone. Photograph taken in summer (June): 1) grains; 2) grasses; 3) corn sprouts; 4) pasture

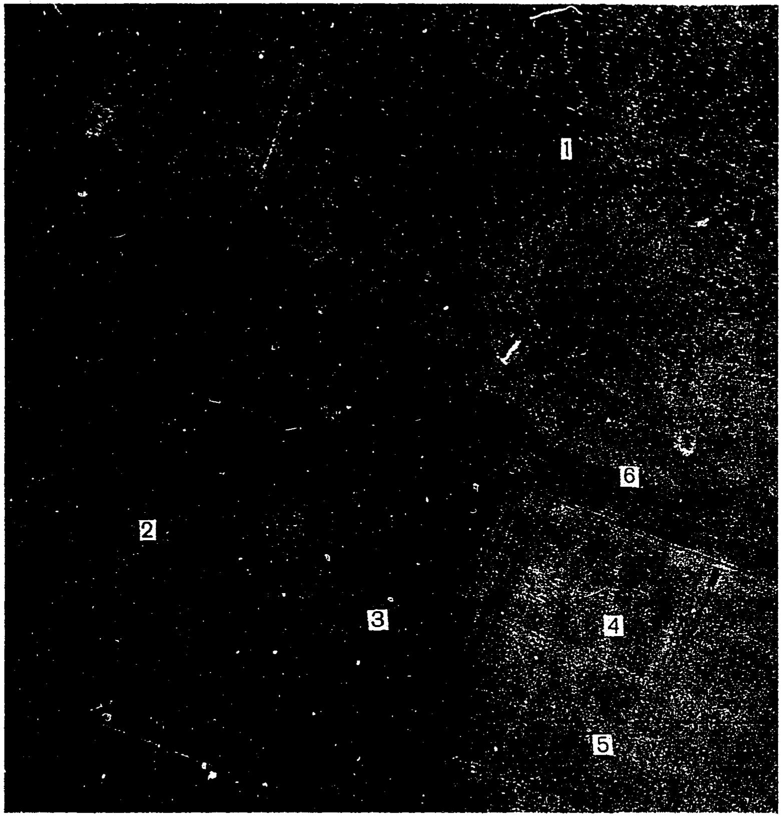

Fig. 17. Spectrozonal aerial photograph of territory of slope along ravine in experimental sector of steppe zone. Survey made in autumn (September): 1) stubble of grains; 2) corn; 3) corn (harvested); 4) grasses; 5) grasses (mown); 6) pasture

Dnepr basins (30-40%). The maximum dissection of the lands with a considerable participation of moderately and strongly eroded soils is interpreted from a photograph in the region of the upper course of the Oskol River (40-50%).

A minimum dissection of lands of the gully-ravine network is a characteristic of watersheds in the neighborhood of the town of Livny (10-20%).

Alluvial-meadow soils of river floodplains show up on the photograph in an almost white tone. Among the agricultural crops a light gray tone is characteristic of fields with winter wheat. An almost white tone is characteristic of fields with winter wheat. An almost white tone is characteristic for plantings of perennial grasses (sweet clover, clover, timothy, alfalfa). A gray tone corresponds to fields of spring wheat, barley and a vetch-oat mixture. Forests and virginland vegetation of the meadow steppe do not differ and show up in a light gray tone.

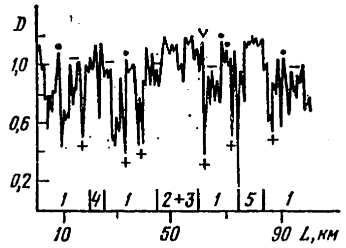

Fig. 18. Microphotometric profile obtained from space photograph from ERTS-1 satellite in spectral zone 0.7-0.8μm. Survey time 10 May 1975. 1) typical chernozems, leached chernozems and meadow-chernozem soils; 2, 3) gray and dark gray forest soils with participation of poorly consolidated sands and alluvial meadow soils; 4) alluvial meadow and meadow-swampy soils; 5) clouds. Fields: + plowed and sprouts of agricultural crops; o planted in winter wheat; - planted in spring crops; V in alfalfa.

A microphotometric profile which we obtained from this space photograph of an experimental sector of the steppe zone and the territories adjacent to it makes it possible to distinguish the following.

On the basis of the nature of the trace pattern it is possible to identify typical and leached chernozems and meadow-chernozem soils from gray forest soils with the participation of consolidated sands and areas of alluvial meadow and meadow-swampy soils (Fig. 18).

Among the agricultural plantings it is possible to determine fields with stands and sprouts of agricultural crops which do not mask the surface of chernozems. On the trace they give sharp peaks pointing in a downward direction. Diametrically opposite peaks on the trace are formed by fields occupied by alfalfa and winter wheat. It was demonstrated that in the zone

0.7-0.8 μm these crops during the spring period show up in a light, almost white tone. The middle segments of the curve with poorly expressed peaks correspond to the image of plantings of spring crops.

An analysis of the photoimage of the space photograph taken in the IR spectral zone (0.8-1.1 μm), in comparison with the just examined photograph, did not reveal special fundamental differences with respect to the interpretation of soils and plantings of agricultural crops.

On a late summer space photograph, taken in the zone 0.7-0.8 μm, as indicated by our investigations, an almost black tone corresponds to the plowed surface of typical chernozems and meadow-chernozem soils (Table 21). Considerable spaces on the photograph have a light gray photoimage tone which corresponds to fields covered with the stubble of grain crops. Against a light gray background through virginland vegetation it is virtually impossible to interpret meadow-chernozem soils associated with longitudinal troughs and ravines, as was demonstrated for the spring period. On the basis of a light gray tone it is possible to discriminate areas of gray and dark gray forest soils. On the basis of an almost white tone there is reliable interpretation only of alluvial-meadow soils of such large steppe rivers as the Seym. Small steppe rivers, as well as the nature of the erosional dissection of the territory, are not determined from the summer photograph or are interpreted unreliably.

Among the agricultural crops fields of corn, sugarbeets and alfalfa have an almost white tone. Fields of harvested corn have a gray tone. Forests and virginland steppe show up in a light gray, almost white tone.

Clouds are a considerable obstacle to the successful interpretation of the soil cover and agricultural crops; these show up on the photographs in a gray tone, whereas the shadows cast from clouds onto the earth's surface have an almost black tone. It is very difficult and sometimes almost impossible to use a summer photograph in the zone 0.7-0.8 μm to interpret the presence of small cumulus clouds. On the ground the shadows from it show up as small spots of an almost black tone which with respect to image tone merge with plowed fields with chernozems and meadow-chernozem soils.

The photoimage of the soil-vegetation cover on a space photograph taken in the red zone of the electromagnetic spectrum (0.6-0.7 μm) has a fundamentally different character in comparison with the photograph just considered. On this photograph a gray tone shows sectors of bare fallow and plowed fields with a direct image of the soil surface.

Against a general gray and light gray background of the photograph, against an almost white or light gray tone along the right bank of the Oskol, Rat' and Tuskar' Rivers, it is easy to interpret gray and light gray forest soils with the participation of eroded soils and semiconsolidated sands. In the IR zone fields with corn, sugarbeets and alfalfa have an almost white tone; in the red zone they appear in a dark gray or almost black tone.

The stubble of grain crops and corn, due to the high reflectivity of straw and afterharvest remnants, is interpreted from a light-gray or almost white image tone. The forests have an almost black tone, whereas the virgin land of mixed grass vegetation has a gray tone. Accordingly, on this photograph they are easily discriminated from one another. The images of alluvial-meadow soils of the floodplains of such steppe rivers as the Seym are characterized by gray and dark gray tones with a poorly discriminated internal differentiation of the soil-vegetation cover on the floodplain. The clouds on this photograph show up in a white tone but their shadows are almost black, which makes it difficult to discriminate them from forest areas.

A comparative analysis of the space photographs taken at different survey times indicated that they mutually supplement and enrich one another with respect to a more complete transmission of information on the soil and agricultural resources of the investigated natural regions. It was established that the surface of typical chernozems and meadow-chernozem soils on both spring and on summer photographs shows up in a dark gray tone in the range 25-30 units of the gray tone level, whereas fields of alfalfa and perennial grasses have an almost white tone, equal to 50-60 units. Additional significant data on the soil-vegetation cover can be obtained when using space photographs of different spectral survey zones.

Chapter 5

INVESTIGATIONS OF SOILS FROM SPACE PHOTOGRAPHS

During recent years there has been ever-increasing use of space photographs and methods for remote observations in agriculture both in our country and abroad.

Fundamental Russian publications (Beregovoy, et al., 1972; Vinogradov, Kondrat'yev, 1971; Gonin, Strel'nikov (editors), 1975; Grigor'yev, 1975; Vinogradov, 1976; ISSLEDOVANIYE PRIRODNOY SREDY KOSMICHESKIMI SREDSTVAMI, 1973, 1974, 1975, 1976; Rodionov (editor), 1973; METODY DESHIFRIROVANIYA, 1976; ISPOL'ZOVANIYE KOSMICHESKIKH..., 1977; Kravtsova, 1977; KOSMICHESKAYA S"YEMKA..., 1979; AEROKOSMICHESKIYE..., 1979) examined the general problems involved in the interpretation of space surveys, including their use in the study of the soil and vegetation cover. Abroad these matters have been dealt with in systematic aids (MANUAL OF REMOTE SENSING, 1975; Barrett, Curtis, 1976).

Space methods ensure broad possibilities for obtaining information on the use of terrestrial resources in agriculture (Table 22).

Soviet and American specialists in the field of use of space photographs for agricultural purposes assume that about 90% of the data necessary for rational land use can be obtained using aerospace methods. The latter make it possible to identify the principal categories of use of agricultural lands: cultivated lands with different types of agricultural crops, meadows, pastures, fallow lands, etc. Remote methods constitute an important tool for the successful solution of agricultural problems.

In 1968 the US Department of Interior outlined a program for investigating natural resources using artificial earth satellites of the EROS type (Earth Resources Observation Satellite), a satellite for observing the earth's resources. In addition to NASA, the US Department of Agriculture and other departments are taking an active part in this program.

One of the principal aspects of this program is obtaining the space photographs necessary for compiling and revising different types of special maps (Colvocoresses, 1975). This objective is one of the most important as well in the Soviet program for the use of space materials (Bryukhanov, Makhin, 1973; Salishchev, et al., 1975; Kiyenko, Kel'ner, 1976; Zonn, 1977; Knizhnikov, Kravtsova, Fivenskiy, 1975; PRIMENENIYE..., 1978).

In the US and USSR space programs for the study of natural resources great attention is being devoted to solution of practical problems. Below we will describe a number of matters which are being dealt with in this program for the use of space materials in the field of agriculture.

The inventorying of agricultural fields provides for investigations for measuring the areas of agricultural fields, establishing the boundaries between fields and wooded areas, preparation of maps showing agricultural crops, and also compilation of special speedily prepared maps of agricultural fields based on satellite data.

The estimating of the yield of agricultural crops provides for investigations of the use of space data for determining the state of virginland vegetation and agricultural fields, the degree and area of weediness and diseases of agricultural crops, shortages of moisture for growing vegetation, and also for routine monitoring of the state of wintering of winter crops, estimation of the productivity of hay fields and pastures.

Improvement in use of arable land. In solving this problem plans call for investigations for studying the structure of the tilled soil layer, for determining soil moisture content and temperature, the needs of soils for drainage and irrigation, degree of erosion and salinization of soils, for evaluating the results of recultivation of soils, for determining the regions subjected to frosts and the falling of precipitation, for detecting the shortage of nutrients in the soil, for the mapping of different types of soils with clarification of structure of the soil cover, for regionalization of soil resources.

The soil-agricultural interpretation of photographs taken from space makes it possible to have data on a global and regional scale on the soil cover and on plantings of agricultural crops. Among the specific properties of soil-agricultural intermination are extensive coverage, small scale and generalization of the photoimages of features.

Coverage of Space Photographs and Study of Soils

In comparison with materials from an aerial survey, space photographs cover enormous areas of the earth's surface. Depending on the frame format, focal length of the objective and survey altitude the area covered by one photograph will be different. Space photographs of extensive territories of the earth for the first time are making it possible to see objectively the nature of the soil cover of individual regions and provinces, individual mountain systems and the vertical zonality associated with them.

On a space photograph of the territory of the southwestern part of Morocco, obtained as a result of flight of the "Gemini-5" spaceship from an altitude of about 280 km at a scale of ~1:900,000, it is easy to see the coastal region near Sidi Ifni and the marginal part of the Atlas and Antiatlas mountain system (Fig. 19, 19a). The comparison of this photograph with the soil map of Morocco at a scale of 1:15,000,000 which we made indicated the possibility for a substantial refinement of the soil cover in this region on the basis of space photographs for the lowland and mountainous parts of the territory. Mountain cinnamon soils and mountain cinnamon soils eroded to different degrees are formed here under subtropical forest or scrub. Beneath forests these soils appear on the photograph as dark gray and under thin forest in a gray tone with a folded-corroded structure of the photoimage characteristic for mountainous areas.

In the northwest, in the coastal sector, the Antiatlas Mountains border an extensive lowland with elevations less than 200 m. The vegetation is represented by thin forest with the argan tree, thorny scrub with a predominance of acacia and jujuba, as well as desert-adapted grass associations. Cinnamon soils, gray soils of subtropical semideserts, irrigated gray soils of oases and black subtropical soils are developed here. On a space photograph, against the uniform gray background of the image of the desert landscape of the coastal lowland with its cinnamon soils, it is easy to see dark spots -- sectors occupied by oases. The gray soils of the subtropical semideserts have a light gray tone of the photoimage. A dark gray tone clearly reveals the moister sectors of irrigated gray soils and black subtropical soils. A lowland with sandy soils extends in a narrow band along the Atlantic coast in the lower part of the photograph.

Another space photograph, taken during the flight of the "Gemini-4" spaceship over the territory of Oman, in great detail (at a scale 1:750,000) reveals the nature of the earth's surface in the eastern part of the Arabian Peninsula (Figures 20, 20a). We carried out soil interpretation using a soil map of Asia based on black-and-white and color photographs. The altitude of the survey was 180 km; the area of the survey was 22,500 km^2. The color photograph clearly shows sand dunes in a reddish-yellow color with the crests extending from north to south for tens and hundreds of kilometers parallel to the prevailing wind direction. Chains of mountains rise sharply from them to the northeast; these mountains of Oman rise up to 3,000 m. These mountains are made up of limestones, marls and shales with outcrops of volcanic rocks. The vegetation is very sparse. The soil cover is represented by reddish-brown mountain soils of the savanna and is characterized by extensive occurrence of rock debris.

The photograph clearly shows a finely corroded folded dendritic pattern of a gray tone associated with erosional dissection of the surface, the direction of the mountain folds and dry valleys. A very rocky foothill zone around the mountains with a width of about 20 km is clearly interpreted from the more uniform-homogeneous pattern. Dry rocky wadis are represented on the photograph by the light-colored veins of the dendritic pattern. Reddish-brown desert-adapted savanna soils are formed in the foothill sector. Along the southeastern part of the peninsular coast the light gray tone on the photograph represents a zone with coastal off-shore bars and gentler relief forms than in the foothill and especially in the mountainous part of the territory. This zone consists of soils of the tropical deserts, and in the sector transitional to the mountains there are reddish-brown desert-adapted savanna soils. Individual small spots and dark points along the boundary of dunes and along the coast correspond to cultivated oases. Swamps, lagoons and residual lakes have the darkest tone on the photograph.

Fig. 19. Space photograph of territory of southwestern Morocco adjacent to Atlantic Ocean. Scale ~ 1:900,000. Survey made from "Gemini-5" spaceship.

The mountain and foothill zone, coastal strip and zone of sand dune occurrence are reliably discerned in general on the space photograph on the basis of the nature of the earth's surface and soil cover (its structure and different erosional dissection).

It was established in our investigations of space photographs of mountainous regions that the vertical zonality of the soil-vegetation cover is clearly traced from them. For example, from a comparison of space photographs of Altayskiy Kray taken during flight of the "Salyut" orbital station in the summer of 1971 and soil maps of this region, taking into account the change in the gray phototone and the image pattern, it is possible to see the transition from mountain gray forest soils formed under the dark coniferous mountain forests of Southern Siberia, to mountain and ordinary chernozems, partially tilled or occupied by mountain meadow steppes.

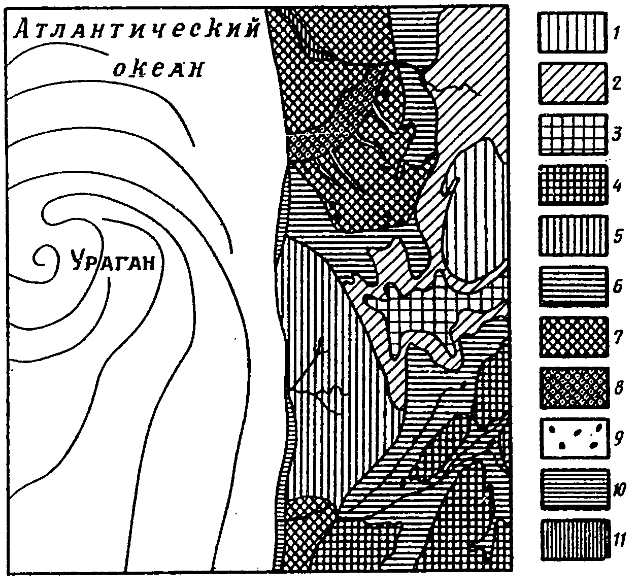

Fig. 19a. Interpretation of soil cover from space photograph of territory of southwestern Morocco adjacent to Atlantic Ocean. Soils: 1) mountain reddish-cinnamon and cinnamon; 2) mountain reddish-cinnamon and eroded cinnamon; 3) mountain reddish-cinnamon, cinnamon and reddish-brown; 4) mountain cinnamon; 5) reddish-cinnamon and cinnamon; 6) cinnamon and gray-cinnamon; 7) gray-cinnamon and black subtropical; 8) gray soils of subtropical semidesert; 9) gray soils of irrigated oases; 10) sandy coastal zone of ocean; 11) alluvial.

The lower zone of steppe expanses of the analyzed territory is represented by southern chernozems, dark chestnut and chestnut soils with a high percentage of solonetz. In the lowland part, against the general gray and light gray image background of the image of chestnet and solonetz soils, on the basis of the dark granular pattern of the photoimage and the extended linear form of the contours, it is easy to distinguish sandy unconolidated soils formed under steppe-adapted band pine forests which occur along the channels of ancient watercourses.

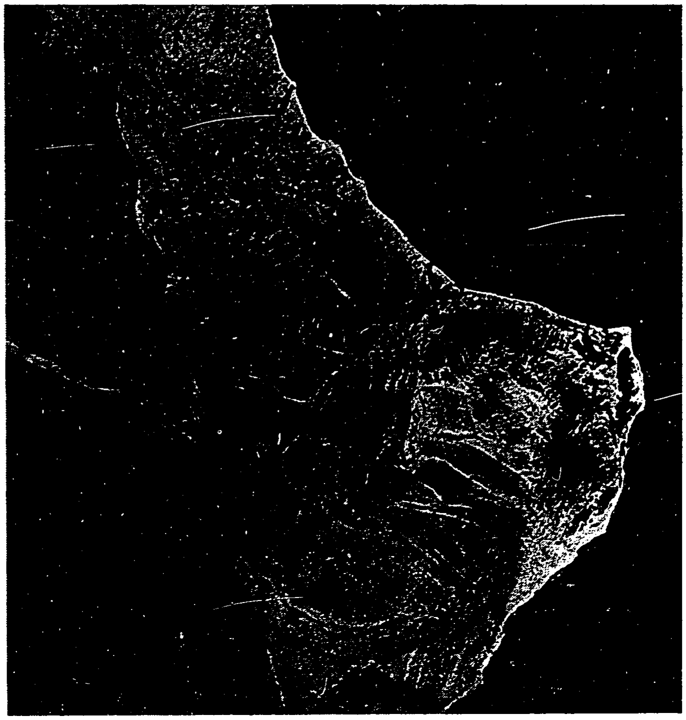

Fig. 20. Space photograph of eastern part of Arabian Peninsula in region of Cape Guardafui (Ras Assir). Scale 1:750,000. The survey was made from the "Gemini-4" spaceship.

Small Scale Properties and Generalization of Soil Photoimage

An important characteristic of a space survey is that the photographs are small scale. The photographs may be of a very small scale, about 1:10,000,000 - 1:100,000,000 and smaller, with great generalization not only of the soil-vegetation cover, but also relief forms on the earth's surface. Such photographs are used for scanning purposes. Both in our country and abroad rather extensive use is made of small-scale photographs at a scale of 1:1,000,000 - 1:2,500,000. These space photographs can be used in small-scale soil mapping. The optical generalization of the soil cover, which is reflected in the nature of the photoimage of these photographs, makes possible successful interpretation and mapping of zonal and especially intrazonal soils and detection of eroded and salinized sectors revealing a different character of agricultural land use.

Table 22

Possibilities of Use of Space Research Methods in Agriculture
(AGRICULTURAL APPLICATIONS..., 1967)

Field of application	Necessary resolution relative to maximum possible theoretical resolution in:		Interpretation methods	
	photographic methods	IR and infrathermal methods	photographic	IR and infrathermal
Determination of principal types of land use	Minimum		Developed	Not developed
Observation of soil cover	"		Same	Same
Observation of water resources	"		"	"
Mapping	Minimum	Unsuitable	"	"
Observation of state of pastures	Minimum		Partially developed	"
Observation of agronomic conditions	"		Same	
Determination of types of agricultural crops	Average	Minimum	"	
Observation of intensity of development of agricultural crops	Maximum		"	
Determination of yield of agricultural crops	"		"	
Observation of farm animals	"		Not developed	

Table 23. Interpretation Criteria for Soils for Space Photograph and Aerial Photographs (Table-Key). Survey Time -- Late Spring and Early Summer. Photographs: Black-and-White (Isopanchromatic). Aerial Survey Scale: Medium. Space Photograph Scale: Small

	Soil	Relief	Почвообразующая порода 1	Растительность, с.-х. угодье 2	Глубина грунтовых вод, м 3	Глубина образца, см 4	pH водной 5
11	Чернозем мицеллярно-карбонатный сверхмощный	Слабовыпуклый водораздел 17	Лессовидные отложения 23	Пашня 29	Более 10 м 31	0—25 30—40 60—70 90—100 160—170	7,9 7,9 8,4 8,3 8,5
12	Лугово-черноземная выщелоченная сверхмощная	Узкая плоская ложбина 18	Делювиальные отложения 24	Пашня	Более 10 м, временное поверхностное увлажнение 32	0—25 30—40 50—60 90—100 150—160	6,9 7,2 7,9 7,2 7,6
13	Лугово-черноземная осолоделая среднемощная	Плоская западина 19	Делювиальные отложения 25	Пашня	Более 10 м, периодическое поверхностное 33	0—25 30—40 55—65 90—100 170—180	6,5 6,9 7,5 7,5 8,4
14	Черноземно-луговая выщелоченная	Терраса, плоские участки 20	Древнеаллювиальный суглинок 26	Пашня	2 м	0—25 30—40 60—70 90—100 190—200	6,8 7,1 7,1 8,0 8,9
15	Солонец луговой солончаковатый	Терраса, микроповышения 21	Древнеаллювиальный суглинок 27	Пашня	2,5 м	0—20 30—40 50—60 120—130 170—180	8,8 8,5 9,6 9,9 9,5
16	Солончак луговой	Притеррасное понижение 22	Засоленные делювиальные глины 28	Солянково-полынный комплекс 30	1,5 м	0—2 2—7 20—30 50—60 75—85 110—120	10,6 10,5 10,3 10,2 10,0 10,2

Гумус, %	Емкость поглощения, мэкв/100 г почвы	CO_2, %	Сумма солей, %	Механический состав (%) частиц, мм		Interpretation criteria	
				<0,001	<0,01	air photos	space photos
5,0	33,6	Не опр.	Нет 35	48	79	Однородный темно-серый тон на парах и разная тональность на полях с посевами. Контуры крупных размеров 36	Однородный темно-серый тон фотоизображения, характерный для черноземов мицеллярно-карбонатных 42
34 Не опр.	34,1	0,7	»	48	78		
4,7	21.4	3,9	»	52	82		
3,8	19,8	3,5	»	52	79		
2,1	21,9	3,8	»	53	82		
6,9	24,7	Нет		41	58	Контуры узкой вытянутой древовидной формы более темного тона, чем окружающие участки с черноземами 37	Контуры лугово-черноземных почв не видны из-за оптической генерализации 43
4,6	22,9	» 35		Не опр.			
34 Не опр.	22,4	»		»	» 34		
2,9	21,6	»		»	»		
1,4	18,3	»		»	»		
2,7	12,6	»		49	66	Пятнистоокруглая форма контуров, размер небольшой. Светло-серый тон при распашке почв и серый под растительностью 38	
1,1	14,8	»		54	85		
1,4	14,6	»		53	84		
1,0	13,6	»		65	88		
Не опр.		»		Не опр.			
2,3	10,4	Нет 35		28	47	Темно-серый тон, местами серый у контуров легкосуглинистого механического состава 39	Неоднородный рисунок темно-серого и серого тона 44
1,5	9,9	»		30	42		
1,6	9,1	0,1	Нет	28	38		
0,8	Не опр.	1,2	»	27	—		
Не опр.	3,4	3,4	»	21	28		
2,3	10,7	2,5	0,35	30	45	Узорчатый пестрый изъеденный рисунок контуров светло-серого тона, размеры контуров мелкие 40	Контуры вытянуты вдоль долин степных рек. Комплексность почв террасы и поймы интегрируется 45 46
0,8	12,8	1,5	1,83	26	50		
0,6	11,1	6,2	0,97	39	56		
Не опр.	8,6	4,9	1,02	33	48		
»	8,0	2,6	Не опр.	27	38		
1,1	Не опр.	4,2	3,46	Не опр. 34		Ярко-светлый тон из-за выцветов корочки солей на поверхности почвы 41	
1,7	» »	4,0	Не опр.	»	»		
0,6	» »	4,6	1,37	»	»		
0,6	» »	6,7	Не опр.	»	»		
0,6	» »	7,0	0,99	»	»		
0,3	» »	5,8	Не опр.	»	»		

Soil	Relief	Почвообразующая порода 1	Растительность, с.-х. угодье 2	Глубина грунтовых вод, м 3	Глубина образца, см 4	pH водной 5
47 Аллювиальная слаборазвитая	Пойма, гривистый рельеф 49	Аллювиальные песчаные отложения 51	Пашня 29	Более 3 м 31	0—20 30—40 60—70 90—100 140—150	7,7 7,5 8,2 8,0 8,3
48 Аллювиальная луговая солончаковая	Пойма, плоские участки 50	Аллювиальные суглинки и глины 52	Пашня	Более 2,5 м	0—26 30—40 65—75 115—125 170—180	7,8 7,9 8,0 7,8 7,9

KEY TO TABLE 23

1. Soil-forming rock
2. Vegetation, agricultural crops
3. Depth of ground water, m
4. Depth of sample, cm
5. pH aqueous
6. Humus, %
7. Absorption capacity, meq/100 g of soil
8. CO_2, %
9. Sum of salts, %
10. Mechanical composition (%) of particles, mm
11. Micellar-calcareous extra-thick chernozem
12. Leached, extra-thick meadow-chernozem
13. Solodized, medium-thick meadow-chernozem
14. Leached chernozem-meadow
15. Solonchak-like meadow solonetz
16. Meadow solonchak
17. Slightly convex watershed
18. Narrow flat trough
19. Flat swale
20. Terrace, flat sectors
21. Slightly raised terrace
22. Depression near terrace
23. Loessial deposits
24. Talus deposits
25. Talus deposits
26. Ancient alluvial clayey loam
27. Ancient alluvial clayey loam
28. Saline deluvial clays
29. Cultivated land

Table 23 (continued)

Гумус, % 6	Емкость поглощения, мэкв/100 г почвы 7	CO$_2$, % 8	Сумма солей, % 9	Механический состав (%) частиц, мм <0,001	<0,01	10 Interpretation criteria air photos	space photos
0,7	7,5	0,1	Нет	19	25	Светло-серый тон из-за опесчаненности, форма контуров серповидная, межгривистые понижения серого и темно-серого тона	
0,3	5,5	0,2	» 40	20	25		
0,3	4,2	5,2	»	20	32		53
34 Не определяли			»	Не опр.			
Не опр.	3,0	2,6	»	15	16		
2,9	24,4	0,9	Не опр.	33	59	Серый тон фотоизображения со старицами темно-серого тона и лугово-болотными почвами	
1,4	25,0	Не опр. 34	»	65	83		54
1,3	23,9	1,3	34 Не определяли				
0,9	Не опр.	1,3	»	34 »			
Не опр.	25,4	1,8	»	»			

KEY TO TABLE 23 (continued)

30. Russian thistle-wormwood complex
31. More than 10 m
32. More than 10 m, temporary surface moistening
33. More than 10 m, periodic surface moistening
34. Not determined
35. No
36. Uniform dark gray tone on fallow and different tonality on fields with crops. Large soil units
37. Soil units of a narrow elongated dendritic form of a darker tone than the surrounding sectors with chernozems
38. Spotty-rounded form of soil units, small size. Light gray tone in case of plowed fields and gray tone in case of vegetation
39. Dark gray tone, locally gray for soil units of light clayey loam mechanical composition
40. Figured, mottled, serrated pattern of soil units of light gray tone, small size of soil units
41. Bright-light tone due to efflorescence of crust of salts on surface
42. Uniform dark gray photoimage tone characteristic for micellar-calcareous chernozems
43. Areas of meadow-chernozem soils not visible due to optical generalization
44. Nonuniform pattern of dark gray and gray tone
45. Soil units elongated along valleys of steppe rivers
46. Complexity of soils of terrace and floodplain is integrated

KEY TO TABLE 23 (continued)

47. Alluvial poorly developed
48. Alluvial meadow solonchak-like
49. Floodplain, crested relief
50. Floodplain, flat sectors
51. Alluvial sandy deposits
52. Alluvial clayey loams and clays
53. Light gray tone due to sand permeation, form of soil units crescent-shaped, intercrest depressions of gray and dark gray tone
54. Gray tone of photoimage with cut-off meanders of dark gray tone and meadow-swampy soils

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Table 24. Interpretation Criteria for Soil Cover of Kazakhstan and Altayskiy Kray for Space Photograph Taken from "Salyut-1" (Table-Key). Survey Period Early Autumn. Small Scale. Black-and-White Photograph (Film Type 18)

Soils	Relief	Vegetation	Interpretation Criteria
Mountain gray forest	Mountain ridges and ranges with different exposure	Mountain aspen-birch-fir forests	Dark gray tone with clearly expressed dendritic erosional photoimage pattern
Ordinary and gravelly chernozems	Sloping-ridged "socle" plains and Altay low mountains	Mixed-grass-soddy-grassy steppe, alternating with high scrubby steppes on southern slopes and meadow-steppe highly scrub-covered on northern slopes	In plowed sectors -- rectangular-spotty pattern corresponding to field ridging. Mechanical composition of soils heavy and deflated striated structures are absent In low mountains on the northern slopes -- a dark gray tone, on the southern slopes -- a wedgelike-contrasting texture with light spots of exposed gravelly-rocky sectors
Southern clayey loam chernozems	Areas of loessial plateaus of dry steppe zone	Agricultural crops -- spring wheat, barley, oats (tone light gray); corn (dark gray); perennial grasses (almost black); fallow (light)	Interpretation criteria similar to chestnut soils: rectangular-spotty pattern corresponding to ridging of fields. Tone of fields mottled from light to almost black. General nature of photoimage of gray tone

Table 24 (continued)

Soils	Relief	Vegetation	Interpretation criteria
Southern chernozems and dark chestnut sandy loam and sandy	Hilly-dune relief amidst loessial plateaus	Psammophytic dry steppe	Mottled, locally small-spotty pattern of gray and almost white photoimage tone characteristic for deflatable sandy sectors. The soil units have an elongated cigar-shaped form
Southern chernozems and steppe solonetz soils	Denudation-"socle" plain	Sheep's fescue-feathergrass steppe with participation of halophytic associations of stinking ground pine, biyurgun and summer cypress	Fine spotty contrasting texture of gray tone
Chestnut clayey loam	Leveled areas of loessial plateaus of dry-steppe zone	Agricultural crops: spring wheat, barley, oats (light gray tone)	In cultivated areas rectangular-spotty photoimage pattern of fields. Interpretation criteria similar to southern chernozems, but general character of photoimage of light gray tone
Chestnut sandy loam and sandy with participation of eroded (deflated) soils	Ancient alluvial plains	Psammophytic-feathergrass dry steppes	Striated-undulating dune pattern of light gray tone. Very limited cultivation of lands. "Banded" fields characteristic for areas with shelterbelts

Table 24 (continued)

Soils	Relief	Vegetation	Interpretation criteria
Soddy-slightly podzolic, soddy-slightly podzolic eroded sandy (pine-covered sands) and soddy-podzolic-gleyey	Longitudinal ancient runoff troughs and their delta broadenings	Steppe pine forests on sand, elongated in nature	Nonuniform, locally cellular pattern of dark gray tone with participation of deflatable pine-covered sands of light gray and almost white tone. Soil units have longated form with sharply defined boundaries
Meadow-swampy and meadow-swampy solonchak-like	Lacustrine and marginal depressions along edges of ancient runoff troughs	Moist meadow vegetation	Dark gray photoimage tone. Small soil units of rounded-spotty form
Solonchaks and meadow solonchak-like soils	Lacustrine and circumlacustrine depressions. Mouths of ravines on terraces of ancient runoff troughs	Russian thistle and halophytic meadows with lyme grass	Uniform, almost white tone of photoimage caused by presence of salt crust on soil surface
Alluvial-meadow and alluvial meadow solonetz-like and meadow-swampy soils of ox-bow lakes	High floodplain of steppe river	Mixed-grass-grass meadow vegetation undergoing steppization process	Meander-ox-bow lake pattern of gray and light gray tone with conspicuous ox-bow lakes of dark tone
Alluvial-meadow and alluvial-moist meadow, meadow-swampy and swampy	Low floodplain of steppe river	Mixed-grass - grass meadow and swampy vegetation	Meander-segmental pattern of dark gray tone with presence of individual ox-bow lakes

Table 25. Interpretation Criteria for Soil Cover of Northwestern Part of Kazakhstan Obtained from Space Photograph (Table-Key). Survey Period -- Spring. Medium Scale. Black-and-White Photograph (Type 17 Film)

Soil	Relief	Vegetation	Interpretation criteria	Difference in levels of gray tone relative to solonchaks
Dark chestnut sandy loam and meadow-chestnut solonetz-like with participation of solonchaks	Undulating sandy plain with numerous bitter salt lakes	Virginland sheep's fescue-feathergrass-mixed grasses; wasteland of sheep's fescue-feathergrass-crested wheatgrass; cultivated land (rare)	Moiré pattern of gray and light gray tone. Northeasterly direction of clear bands. Numerous spots of almost white tone and crescent-shaped sectors along edge of lakes -- image of solonchaks	Dark chestnut sandy loam -- 24; meadow-chestnut -- 28
Dark chestnut sandy loam, meadow-chestnut solonetz-like and steppe solonetz and meadow-steppe solonetz	Slope of undulating sandy plain toward ancient runoff trough	Cultivated land -- areas of perennial grasses, cultivated crops and less frequently grain crops	Combination of moiré and complex pattern of gray and light gray tone. There are solonetz-like sectors with sharply defined serrated pattern	Dark chestnut and meadow-chestnut solonetz-like -- 24; solonetz -- 7
Dark chestnut solonetz-like, meadow-chestnut solonetz-like, steppe and meadow-steppe solonetz	Ancient runoff trough. Slightly undulating plain complicated by micro- and mesodepressions and residual hills	Cultivated lands -- areas of perennial grasses; partially virginland mixed grasses-sheep's fescue-wormwood with thrift	Complex nature of photoimage with serrated, sharply defined pattern of light gray, gray and dark gray tone. Fine details	In cultivated areas: dark chestnut solonetz-like -- 16; meadow-chestnut -- 21; solonetz -- 10

Table 25 (continued)

Soil	Relief	Vegetation	Interpretation criteria	Difference in levels of gray tone relative to solonchaks
	in large mesodepressions -- bitter salt lakes			
Dark chestnut sandy and solonchaks	Extensive ancient runoff trough with numerous sandy ridges and microswales	Virginland sheep's fescue-feathergrass-mixed grass with wormwood-solonchak vegetation on solonchaks	Clearly expressed moiré pattern of light gray and gray tone with small bright-white spots of solonchaks The moiré pattern has a NE orientation governed by general orientation of sandy ridges in depressions between ridges	Dark chestnut sandy -- 13
Meadow solonetz-like	Bottoms of existing runoff troughs amidst complex territories	Quack grass-mixed grass with thrift	Trough-dendritic form of soil units of dark gray tone	Meadow-solonetz-like -- 27
Solonchaks	Marginal parts of bitter salt lakes and their bottoms during dessication	Wormwood-Russian thistle	Spotty or crescent-shaped form of soil units, tone almost white for dessicated surface covered by salts	

Table 25 (continued)

Soil	Relief	Vegetation	Interpretation criteria	Difference in levels of gray tone relative to solonchaks
Dark chestnut calcareous clayey and meadow-chestnut calcareous soils of swales	Plateaus with flat micro-swales	Cultivated land -- plantings of grain crops	Dark gray, gray and light gray tone with numerous squares of field images. Level of gray tone different in dependence on nature of field working	Dark chestnut calcareous -- 15 and 11; meadow-chestnut calcareous -- 19
Dark chestnut solonetz-like eroded and meadow-steppe solonetz	Steep eroded slopes of eastern exposure of plateaus toward Turgayskaya trough	Mixed-grass-sheep's fescue-wormwood with sea-lavender; island sectors of pine forest	Complex serrated dendritic pattern of gray and light gray tone with mass of erosion troughs and erosional remnants; complex combination of different levels of gray tone	Dark chestnut solonetz-like eroded soils -- 21, solonetz -- 13
Meadow-chestnut solonetz-like and meadow-chestnut solonchak-like eroded	Runoff troughs on eroded slope of plateau toward Turgayskaya trough	Sheep's fescue-wormwood-mixed grasses	Dendritic form of soil units of light gray and almost white tone	Meadow-chestnut solonetz-like and meadow-chestnut solonchak-like eroded -- 13
Dark chestnut solonetz-like, meadow-steppe solonetz and meadow solonetz-like	Southern slope of plateaus to extensive runoff trough, complicated by mesodepressions and troughs;	Virginland -- wormwood-sheep's fescue and quack grass-mixed grass with thrift	Tone gray and dark gray especially around lakes and along present-day runoff troughs. General orientation of soil unit from NE to SW;	Complex of dark chestnut solonetz-like soils, meadow-steppe solonetz and meadow solonetz -- 22

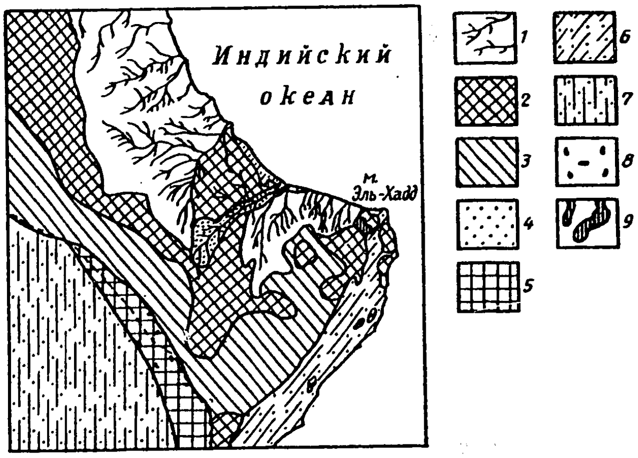

Fig. 20a. Interpretation of soil cover from space photograph of territory of eastern part of Arabian Peninsula in neighborhood of Cape Guardafui (Ras Assir). Soils: 1) mountain reddish-brown savanna soils; 2) mountain reddish-brown soils of dry savannas; 3) reddish-brown highly rocky desert-adapted savannas; 4) reddish-brown desert-adapted savannas of intermont basins; 5) soils of tropical deserts; 6) soils of tropical deserts with sandy off-shore bars; 7) ridged deflatable and semiconsolidated sands; 8) irrigated soils of oases; 9) coastal lagoons and swamps.

Applying specialized photographic systems and artificial earth satellites it is possible to obtain space photographs at the intermediate scale of 1:100,000-1:200,000 which with a high detail impart the image of the soil cover, the nature of the mechanical composition, different humus content, moisture content, erosion and salinization of soils.

At the present time the most widely used scales of space surveys are 1:10,000,000 - 1:1,000,000 or larger. A survey at scales 1:100,000 - 1:1,000,000 is promising for study of the soil cover on a regional basis. The choice of scales of these photographs is determined by the necessary accuracy in soil mapping. An analysis of space photographs taken from the "Soyuz-9," "Soyuz-12" and "Soyuz-22" spaceships and the "Salyut" orbital station indicated that these photographs can be used in compiling and correcting a soil map at a scale of 1:1,000,000.

Data from foreign authors show that materials from the "Apollo-9" spaceship at a scale of 1:3,000,000 were used in compiling a photomap at 1:250,000, whereas the photographic systems of the "Skylab" orbital station ensured the preparation of maps at a scale of 1:118,000 with an initial survey scale of 1:2,500,000.

The problems involved in the generalization of space photographs are inseparable from complex special mapping. In order to compile intermediate- and small-scale soil maps it is desirable to have a scale of space photographs (enlarged from the original by 2^{x}-4^{x} or 3^{x}-5^{x}) identical with the mapping scale (Kravtsova, 1974, 1977). This is associated not only with the technical conveniences for work with space photographs, but also with the similar generalization level.

An important characteristic of a space survey is that on space photographs there is an objective optical generalization of the earth's surface and soil cover. In order to analyze this problem we studied the possibilities of interpretation of the soil cover of the dry steppe zone in the region of the "Tsimlyanskiy" sector on the basis of a space photograph and materials from an aerial survey.

The scale of the space photograph taken from the "Soyuz-9" ship in June 1970 was 1:2,500,000. The scale of the aerial photographs is different. The photographs were black-and-white. In carrying out the work we compared and analyzed the photographic images of different soils on the aerial photographs and on the space photograph for the territory of different natural regions. We analyzed sectors of different water divides, terraces and flood plains of a steppe river. The materials of field checking are given with an indication of the morphological and physicochemical data for the investigated soils (Table 23).

The space photograph and small-scale maps were used in identification and geographical tie-in to the terrain. This was done most easily using a photoimage of the shores of the Gulf of Taganrog, Tsimlyanskoye Reservoir and Lake Manych-Gudilo. The meanders of the lower course of the Don and Manych Rivers show up clearly. Due to cloud cover the Sal River could be traced reliably only in the lower mouth reach; the remainder of the course had to be plotted approximately.

The second element after the hydrographic pattern which could be determined from the space photograph is the character of agricultural use of the territory. On the basis of the degree of land use exploitation it is easy to distinguish three soil-geographic regions: light chestnut soils with a minimum percentage of tilled land, chestnut soils, where exploitation increases sharply to 30-40%, and southern chernozems which are 50-60% tilled. However, against the image background of chernozems it was impossible to see micellar-calcareous thick and very thick soils with plantings of agricultural crops. This is evidently associated with the time of the survey (mid-June). During this period fields with plantings of winter wheat, which predominate in this region, merge on the photoimage with the soil surface.

All three principal components of the soil cover — micellar-calcareous chernozems, meadow-chernozem, meadow-chernozem solothized — in the territory of the Azov-Kuban plain were clearly traced on large-scale aerial photographs. Using medium-scale aerial photographs meadow-chernozem solothized soils, due to the small size of the depressions, were interpreted with difficulty. An analysis of similar soils on a space photograph indicated that in the process of optical generalization the meadow-chernozem soils of hollows and depressions merge into a single contour of a dark gray tone characteristic for the photoimage of micellar-calcareous chernozems.

Another experimental sector took in the marginal watershed eroded part of Sal'sko-Manychskoye interfluve and the terrace of the Manych River. On the aerial photograph the eroded chernozems with a humus content of about 4% show up in a light tone. The soil cover of the terrace is complex. Here there is representation of chernozem-meadow solonetz-like soils with soil-ground water at a depth of 2 m. On the aerial photographs these soils appear in a dark gray tone due to increased moisture content and a quite good supply of humus. Meadow solonchak-like solonetz soils are another component of the soil cover on the terrace. On aerial photographs they show up in a light gray tone of an intricate pattern. A still brighter light tone is characteristic of the image of meadow solonchaks, which at the surface have a salt crust. In general, the terrace photograph has a clearly expressed fine-ribbed intricate pattern characteristic for a complex soil cover with solonetz soils.

An analysis of a similar territory on a space photograph indicated that this complexity of the soil cover and the high percentage of participation of meadow soils, solonetz soils and solonchaks is reflected in a nonuniform pattern of a gray and dark gray tone on the photoimage of the space photograph.

The third experimental sector is the floodplain of the steppe Don River. The floodplain surface has a complex relief consisting of sandy crests, clayey loam depressions between the crests, distributaries, present-day and ancient ox-bow lakes and flat leveled sectors.

Alluvial meadow sandy and sandy loam soils are formed on the sandy crests. On aerial photographs these soils are easily interpreted from the curved form of crests with a bright-light tone. In the more moistened depressions between the crests there is development of alluvial meadow clayey loam sand-permeated soils. On aerial photographs they have a gray or dark gray tone, depending on the degree of moistening and the humus content. On a relatively flat sector of the floodplain, made up of clayey loam and heavy clayey loam saline deposits, there are alluvial meadow solonetz-like and solonetz-solonchak-like soils. On the aerial photographs these soils show up in a gray tone. Against the background of these soils, due to a dark gray tone and a curved crescent shape, it is easy to interpret long, narrow troughs, poorly expressed in the relief, greatly leveled depressions between the crests and silt-filled ox-bow lakes. Alluvial moist-meadow solonetz-like heavy clayey loam soils have developed here. In former ox-bow lakes, well expressed in the relief, there are alluvial meadow-swampy and swampy soils which on an aerial photograph are clearly interpreted due to their affinity to ox-bow lakes and the dark image tone. The photograph showed the first terrace above the floodplain with highly solonetzic combined soils and solonetz soils. The solonetz complex shows up in a mottled pattern with a light gray tone.

A study of the photoimage of this sector from a space photograph indicated that the soil cover of the floodplain and the territory of the first terrace above the floodplain do not differ from one another and show up in a complex pattern of a gray and dark gray tone.

The results of a comparative analysis of small-scale soil maps and the space photograph indicated the following. On the space photograph the area of micellar-calcareous chernozems adjacent to the Gulf of Taganrog shows up in a dark gray tone of a uniform pattern. Southern chernozems have a similar image tone. However, in the areas of southern chernozems it is easy to see rectangles of fields with plantings of agricultural crops. They are particularly clearly visible in the southeastern part of the Sal'sko-Manychskaya Ridge on the boundary with chestnut soils.

Southern chernozems in combination with meadow-chernozem soils, situated on the high terrace of the Don between its valley and the Lower Don Canal, were reliably interpreted from the darkest photoimage tone. This tone, on the one hand, is associated with a considerable humus content (about 4%), and on the other hand, with a high soil moisture content, since a considerable area between the Lower Don Canal and the Don valley is a zone of intensive irrigation.

A considerable area to the south of the Tsimlyanskoye Reservoir, where southern chernozems and especially chestnut soils are encountered, is covered by noncontinuous cloud cover, but it masks the surface image. Only in the region of the southeastern tip of the Sal'sko-Manychskaya Ridge does the cloud cover disappear, and from the photoimage on the space photograph it is possible to determine clearly and map areas of chernozems, chestnut and light chestnut soils. With respect to the image tone the chestnut and light chestnut soils with a high participation of solonetz soils are similar. They show up in a light gray tone, but chestnut soils have a considerably higher percentage of cultivation in the territory. There is very reliable interpretation of the boundary in the neighborhood of Lake Manych-Gudilo between light chestnut soils with a high participation of solonetz soils and southern chernozems. On a space photograph at the western tip of Lake Manych-Gudilo an area of meadow-chestnut soils also stands out sharply against a light gray background of light chestnut soils. It shows up in a mottled pattern of a dark tone with light gray spots.

On space materials a study was also made of the degree of generalization of the soil cover of the dry steppe Zavolzh'ye region. For these purposes use was made of a space photograph at a scale of 1:2,500,000 for the territory of the Syrtovoye Zavolzh'ye steppe zone, taken from the "Salyut-4" orbital station, whereas as a "key" use was made of a soil map of one of the farms of this territory at a scale of 1:25,000 which we compiled earlier (under the editorship of Doctor of Agricultural Sciences V. A. Nosina) using aerial photographs at a scale of 1:17,000. The investigations indicated that on a space photograph on the basis of the different texture of the photoimage there is reliable discrimination of southern chernozems developed on watersheds with areas of eroded soils (complex dendritic texture) and southern chernozems formed on terraces (uniform or widely spaced dendritic texture). The complex pattern of the photoimage of the soil cover of terraces, discriminated from aerial photographs (southern chernozems of different thickness, excavated chernozems, meadow-chernozem soils), on a space photograph had a uniform image of a dark gray tone. On watersheds and terraces on the basis of a dendritic pattern of a light gray tone there is reliable interpretation of eroded and "washed" soils of gullies and ravines and meadow-chernozem soils developed on their bottoms.

As a result of a comparative analysis of the optical generalization process it was established that on space photographs at a scale of 1:2,500,000 for the territory of the Syrtovoye Zavolzh'ye it was possible to determine 5-6 of the soils of the 20 reliably interpreted from large-scale aerial photographs. In the course of generalization there is a quantitative and qualitative selection of soil areas and generalization of their configuration.

In the theory of space interpretation of the soil cover, due to its generalization, it is possible to introduce the concepts of simple and complex integration. The first is characteristic for the representation of soil combinations on a photograph, whereas the second is characteristic of representation of soil combinations and soil complexes on a space photograph.

The joint use of aerial photographs and space photographs of different scales indicates that as a result of optical generalization there is representation of a different structure of organization of the soil cover. At present a study of different types of structures is of theoretical and practical interest for the needs of agricultural production.

Interpretation and Checking the Condition of Soils in Different Natural Zones from Space Photographs

One of the promising directions in the use of space materials in soil science is the development of methods for the quantitative and qualitative inventorying of soil resources, the development of methods for the visual-instrumental soils interpretation of space photographs and monitoring the condition of soils.

The interpretation of soils was carried out with the use of soil maps at medium and small scales, aerial photographs and materials from field investigations. An analysis of space photographs, based on study of the soil cover of the steppe and desert zones, indicated that using them there is reliable interpretation of automorphous, polyhydromorphous, hydromorphous, floodplain alluvial and irrigated soils.

In the steppe zone of Altayskiy Kray and Kazakhstan, on the basis of space photographs at a scale of 1:1,500,000 (and enlarged 4-5^{x}), obtained during the flight of the "Salyut-1" orbital station, there was successful interpretation of a number of soils (Table 24) (in the preparation of this table-indicator in our investigations we used materials from a complex geographic interpretation of space photographs for the purposes of special mapping, work carried out in 1975 at Moscow State University under the direction of K. A. Salishchev.

An analysis of the table shows that the cited soils are interpreted with a different degree of reliability. Soils with a different participation of solonetz are poorly discriminated from one another on small-scale photographs. On the basis of absence of plowing of the soils and a lighter photoimage tone it is possible to make an indirect judgment concerning an increase in solonetz in the soil cover.

It is very easy to see the difference between soddy-slightly podzolic sandy and the main background soils of this territory -- chestnut and southern chernozems; between ordinary chernozems and mountain chernozems and gray forest soils; between alluvial-meadow and meadow-swampy soils of low and high floodplains.

The data in Table 24 show that using interpretation criteria there is a reliable interpretation of meadow-swampy soils and solonchaks. The photoimage tone of solonchaks is bright white, for solonetz soils -- light gray, for meadow-solonchak-like soils -- dark gray, for meadow-swampy soils -- dark gray or almost black.

In microphotometric measurements of a space photograph of the territory of Altayskiy Kray, on the basis of the nature and shape of the spectral curve there is reliable discrimination of chestnut soils and soddy-podzolic sandy soils. Sharp peaks of optical density make possible a clear interpretation of unconsolidated sands subject to deflation. Areas of chestnut and southern chernozems differ from one another due to some decrease (by 0.5-0.7) in the optical density of the latter. Fields with different agricultural crops have a different optical density and in microphotometric measurements a characteristic shape of the curve for each field is obtained (Fig. 21).

A light mechanical composition of chestnut soils (sands and sandy loams) was also determined from the photoimage of the space photograph; sectors of soil subjected to wind erosion stand out especially clearly.

In a soil-agricultural regionalization of a territory it is possible to use small- and medium-scale space photographs. Using space photographs of the territory of the dry steppe zone of the northwestern part of Kazakhstan, obtained during the spring of 1973, we made a study of the soil cover. The interpretation criteria for these soils are given in Table 25. An analysis of the characteristics of the photoimage indicated that using a space photograph, as a result of its extensive coverage and optical generalization, it was possible to determine the principal soil-geographical patterns of this natural region.

The entire territory, on the basis of the photoimage of the soil cover on a space photograph, was subdivided into five major soil-geographical regions. We will now examine the peculiarities of their photoimage.

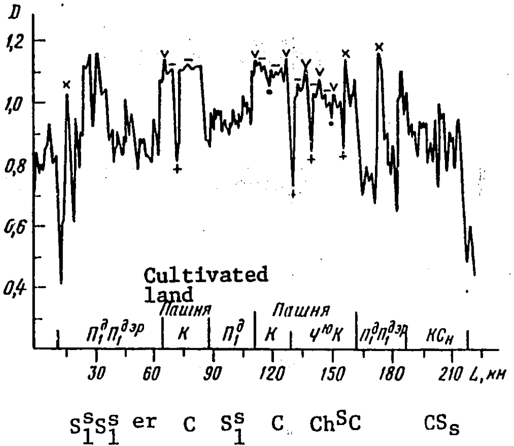

Fig. 21. Microphotometric profile obtained from space photograph from "Salyut" orbital station. Soils: $S_1^sS_1^s$ er -- soddy-slightly podzolic and soddy-slightly podzolic eroded sandy soils; S_1^s -- soddy slightly podzolic sandy soils; C -- chestnut soils; Ch^SC -- southern chernozems and chestnut soils; CS_s-- steppe chestnut and solonetz soils. The fields with a "V" are fallow; - - are plantings of grain crops; symbols: • -- cornfields; + -- perennial grasses; X -- deflated sands.

The first region is characteristic for the territory of an undulating-sandy plain consisting of dark chestnut sandy loam and meadow-chestnut solonetz-like soils. The image of these soils is characterized by a moiré pattern with a light gray and gray tone. The soils are of a light mechanical composition. Considerable areas are occupied by virginland vegetation. This region is characterized by the presence of a great number of small lakes whose marginal parts are salina and meadow solonchaks. Against the gray image background of steppe expanses they are clearly interpreted from the almost white image tone.

The second soil-geographical region takes in the territory of an ancient runoff trough with a complex soil cover which is represented by dark chestnut solonetz-like, meadow-chestnut solonetz-like soils, steppe solonetz and meadow-steppe soils. On a space photograph this soil cover shows up in a complex, sharply defined pattern of a light gray, gray and dark gray tone. It is particularly clearly expressed in cultivated sectors with a direct representation of the soil cover.

The third region is the principal agricultural region. On the photograph it was interpreted from the clearly visible squares of fields, having different tonality in dependence on the nature of soil processing. This is a territory of plateaus with dark chestnut calcareous and meadow-chestnut calcareous soils associated with swales. In the territory of plateaus the number of swales with meadow-chestnut soils increases sharply in the direction from northeast to southwest. The plateaus drop off eastward in a steep scarp in the direction of the Turgayskaya depression.

Fig. 22. Space photographs taken from American meteorological satellite (ITOS-D) NOAA-2 in April 1973 using two-channel radiometer from an altitude of 1,460 km (scale about 1:10,000,000) in visible (0.5-0.7 μm) (at left) and IR (10.5-12.5 μm) (at right) spectral ranges: 1) Caspian Sea; 2) Caspian Lowland with gray-brown desert sandy soils; 3) valley and delta of Ural River with light chestnut, meadow-chestnut solonetz-like and alluvial soils; 4) Ustyurt Plateau with gravelly gray-brown clayey and heavy clayey loam desert soils; 5) solonchak-salina of Kara-Bogaz-Gol Gulf.

On the space photograph it is easy to see this transition from plateau to highly eroded slope. The soil cover of the fourth region is represented by dark chestnut solonetz-like eroded, meadow-chestnut solonetz-like and solonchak-like soils, as well as meadow-steppe solonetz soils. On the photograph the photoimage of the soil cover has a complex serrated dendritic pattern of a light gray and gray tone with a great number of erosional troughs, rills and erosional remnants. With respect to tonality the soil cover is characterized by considerable mottling. Small areas form insular sectors of pine forest having a dark gray photoimage tone.

South of the plateau there is an extensive ancient runoff trough (fifth region). The space photograph clearly conveys the basic NE-SW trend of the sandy ridges and interridge depressions and the direction of the numerous lakes in this part of the territory. Dark chestnut sandy soils and solonchaks have been formed here. There are sectors of deflatable sandy masses. On the photograph this natural region shows up in a clearly expressed moiré pattern with light gray and gray tones. The solonchaks have an almost white tone. The transitional sector of lands from the ancient runoff trough to the plateau on the space photograph has a gray and dark gray tone of a large-spotted pattern. Dark chestnut solonetz-like, meadow-steppe solonetz and meadow-solonetz-like soils have developed here under virginland wormwood-sheep's fescue vegetation.

Thus, on a space photograph of the dry steppe zone during the period of a spring survey there was reliable determination of: a) dark chestnut calcareous and meadow-chestnut calcareous soils of plateaus; b) dark chestnut sandy loam and meadow-chestnut solonetz-like soils of an undulating sandy plain; c) complex soil cover of an ancient runoff trough, represented by dark chestnut solonetz-like, meadow-chestnut solonetz-like and steppe and meadow-steppe solonetz soils; d) amidst the complex soil cover, on the basis of a light tone, areas of steppe solonetz soils, on the basis of a dark gray tone -- areas of meadow and meadow-chestnut solonetz-like soils; e) eroded sectors of the soil cover, represented by dark chestnut solonetz-like eroded soils and meadow-steppe solonetz soils; f) dark chestnut sandy soils; g) solonchaks.

The possibility of interpreting the soil cover of the desert zone from space photographs will be examined on the basis of materials obtained from the "Soyuz-9" and "Soyuz-12" spaceships and the "Salyut-4" orbital station for territories adjacent to Kara-Bogaz-Gol Gulf and also from the American satellite "NOAA-2," which from an altitude of 1,460 km, employing a two-channel radiometer, probes the soil cover in the visible (0.5-0.7 μm) and IR (10.5-12.5 μm) spectral zones.

A comparative analysis of these photographs, made in the course of our investigations, indicated the following. The photographs taken in the visible and IR ranges clearly show the Caspian Lowland with gray-brown desert sandy soils. On the first photograph (Fig. 22, at left) it appears as a nonuniform pattern of a light gray and gray tone with bright-light areas of solonchaks in the neighborhood of Mertvyy Kultuk and Kaydak salinas and in the coastal part of the Buzachi Peninsula.

On an IR photograph the lowland has a dark gray homogeneous tone, against which as light gray sectors and small spots it is easy to discriminate coastal solonchaks and the El'ton, Baskunchak and other salt lakes. On a photograph taken in the visible range these lakes virtually merge with the surrounding territory. In addition, on this photograph the northern boundaries of Ryn sands are sharply defined in the northwest adjacent to Khaki salina; the valleys and deltas of the Volga and Ural with alluvial

Fig. 23. Space photograph of western part of Ustyurt Plateau and Kara-Bogaz-Gol Gulf and interpretation of soil cover from it. Scale 1:2,500,000. Survey made from "Soyuz-9" spaceship in June 1970. Soils: 1) gray-brown solonchak-like, clayey and heavy clayey loam desert soils; 2) gray-brown solonchak-like and leached (elutriated) desert soils; 3) gray-brown solonetz-like, clayey and heavy clayey loam soils; 4) gray-brown solonchak-like, takyr-solonetz-like, leached (elutriated), heavy clayey loam with high gypsum content; 5) mountain gray soils, light gray soils and light gray soils and solonetz-like, clayey loam and sandy loam light gray soils; 6) ridged semiconsolidated sands and solonchaks; 7) gray-brown solonchak-like sandy loam desert soils, hilly-ridged semiconsolidated sands and solonchaks; 8) salina solonchaks; 9) meadow solonchaks.

soils. The considerable solonetzicity of the light chestnut and meadow-chestnut soils situated along the Ural valley is expressed in a uniform gray tone of the photoimage of these areas. On an IR photograph these peculiarities of the soil cover are not traced or are interpreted with difficulty.

Table 26

Boundary Contrast (Interpretability) of Soil Cover of Ustyurt Plateau and Caspian Lowland from Space Photographs Taken from "NOAA-2" Satellite (Scale 1:10,000,000)

Name of bordering territories, soils	Difference in levels of gray tone in spectral ranges (in μm)	
	visible (0.5-0.7)	IR (10.5-12.5)
Caspian Lowland with gray-brown desert sandy soils and solonchaks; valley and delta of Ural River with light chestnut, meadow-chestnut solonetz-like and alluvial soils	10	0
Caspian Lowland with gray-brown desert sandy soils and solonchaks; Ustyurt Plateau with gravelly gray-brown clayey and heavy clayey loam desert soils and solonchaks	0	4
Ustyurt Plateau with gravelly gray-brown clayey and heavy clayey loam desert soils; salina of Kara-Bogaz-Gol Gulf -- solonchaks	5	4

Table 27

Boundary Contrast (Interpretability) of Soil Cover of Territory Adjacent to Kara-Bogaz-Gol Gulf from Space Photograph Taken from "Soyuz-9"

Name of bordering soils	Difference of levels of gray tone
Gray-brown desert solonchak-like and solonchaks	33
gray-brown desert solonchak-like	6
gray-brown desert solonchak-like, leached (elutriated)	18
Salina solonchaks and meadow solonchaks	9
gray-brown desert solonchak-like, takyr-solonetz-like, leached (elutriated), heavy clayey loam with high gypsum content	23

Fig. 24. Space photograph of territory adjacent to Kara-Bogaz-Gol Gulf. Survey from "Salyut-4" in June 1975. Scale 1:2,500,000.

At the same time, using an IR photograph, it is considerably easier to determine the boundary between the Caspian Lowland and the Ustyurt Plateau with gravelly gray-brown clayey and heavy clayey loam desert soils (Table 26). Against the general homogeneous gray image background of the soil cover over the territory of the Ustyurt Plateau the presence of spots of a dark tone makes it easy to interpret depressions occupied by solonchaks and gray-brown solonchak-like sandy loam desert soils and hilly semiconsolidated sands. An analysis of a space photograph taken in the IR spectral zone also indicated that the sandy soils of the Krasnovodskoye Plateau and Karakum sands show up in a dark gray tone similar to the image of the Ryn sands and the sandy expanses of the Caspian Lowland.

Accordingly, the completeness and quality of interpretation of the soil cover from space photographs increase with the use of photographs taken in the visible and IR ranges simultaneously.

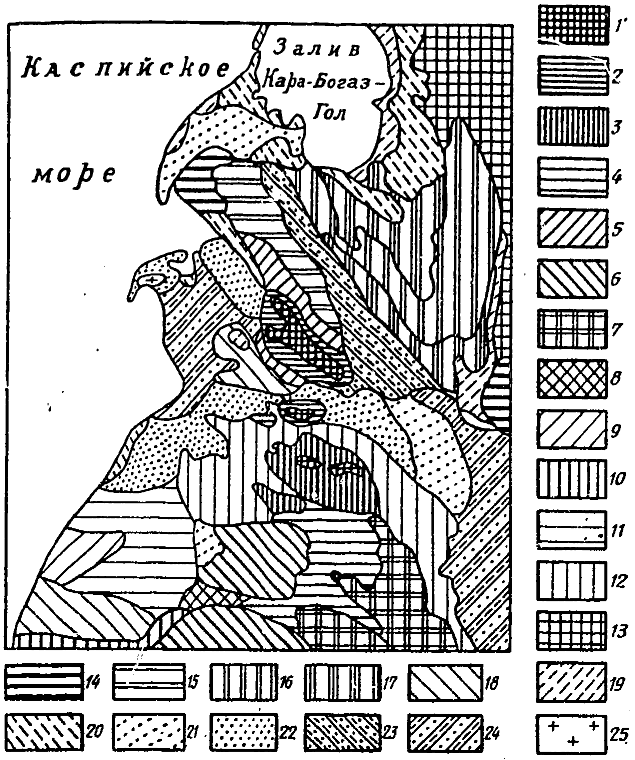

Fig. 24a. Interpretation of territory adjacent to Kara-Bogaz-Gol Gulf from space photograph. Soils: 1) mountain cinnamon; 2) mountain gray soils (dark gray soils); 3) light gray soils on detritus of limestones; 4) light gray soils on ancient clays; 5) light gray soils, medium and slightly clayey loam; 6) light gray soils and typical gray soils; 7) typical gray soils; 8) "blended" saline gray soils; 9) takyrs; 10) takyr-like desert soils; 11) desertified solonchaks and takyrs; 12) takyr-like desert soils, takyrs and solonchaks; 13) typical gray-brown soils, solonchak-like, with high gypsum content, takyr-solonetz-like; 14) solonchak-like gray-brown soils; 16) typical gray-brown soils and solonchaks; 17) gray-brown solonchak-like soils and solonchaks; 18) swampy solonchak-like soils and solonchaks; 19) marsh solonchaks; 20) solonchaks; 21) sands on Paleogene and more ancient rocks; 22) coastal sands on Novokaspiyskiye deposits; 23) sands on Pliocene ancient alluvial deposits; 24) ridged sands and solonchaks; 25) skeletal soils. [Symbol 15 not identified in original]

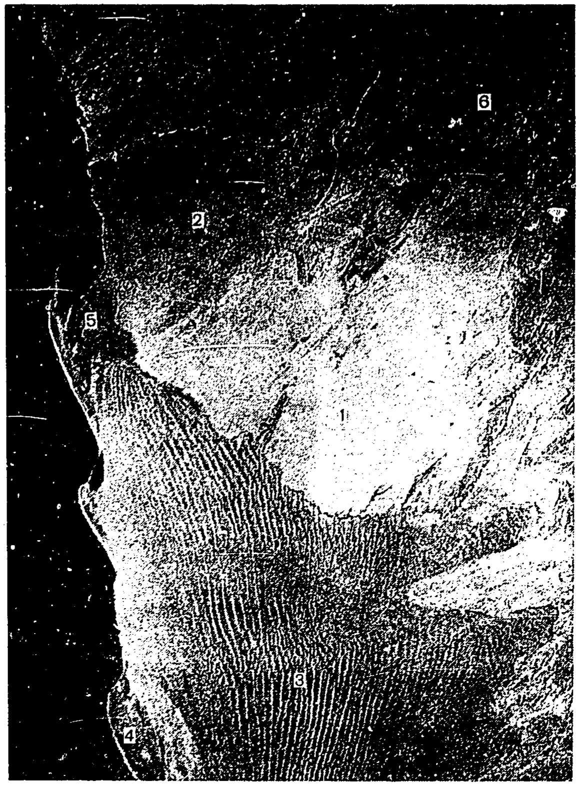

Fig. 25. Space photograph of territory of southwestern part of Africa (Namib Desert). Scale 1:1,000,000. Survey made in autumn (August) from the "Gemini" spaceship. Soils: 1) gravelly-rocky tropical deserts; 2) sandy-gravelly tropical deserts; 3) deflatable ridged sands and semiconsolidated sands; 4) solonchak-like sandy soils and solonchaks; 5) alluvial delta soils; 6) mountain reddish-brown desertified savannas.

On a photograph (scale 1:2,500,000) taken from aboard the "Soyuz-9" spaceship it was easy to see the salt deposits of the Kara-Bogaz-Gol Gulf and the nature of the soil cover in the western part of the Ustyurt Plateau (Fig. 23). In a genetic interpretation of the photograph we used a soil map of Central Asia (scale 1:2,500,000). In a microphotometric study of this photograph on the basis of the nature of the curve and quantitative indices of optical blackening density of the film there was reliable discrimination of gray-brown solonchak-like desert soils and gray-brown solonetz-like soils and solonchaks.

Table 28

Interpretation Criteria for Sowings of Agricultural Crops on Space Photograph Taken from "Salyut-1" (Yanvareva, Nikolayevskaya, 1974)

Plantings or fallow	Form and character of boundaries	Image tone	Image structure	Reliability of determination of features	Comments
Perennial grasses	Rectangular form, clear boundary		Homogeneous	Interpreted	In tone close to floodplain meadows
sowings years 1-2		Dark gray			
sowings years 3-5		Dark gray, almost black			
Wheat, barley, oats	Rectangular form, clear boundaries in crop-rotated fields with regular ridging and indistinct boundaries in fields of irregular form	Gray	Homogeneous, in fields with nonuniform soil cover spotty and striated	Reliably interpreted on plain, in mountains and foothills only in fields of rectangular form	In tone sometimes close to pastures
Corn in tillering phase	Same	Dark gray	Homogeneous	Not always interpreted	In tone close to pastures
Bare fallow	Same	Light gray, sometimes almost white	Homogeneous, sometimes spotty	Interpreted quite reliably	In tone can coincide with solonetz soils on plain

Table 29

Data from Visual-Instrumental Interpretation of Soil Cover of Experimental Sector of Northwestern Kazakhstan from Space Photograph (in Dependence on Nature of Agricultural Working of the Soil) Dark Chestnut Calcareous and Meadow-Chestnut Calcareous Soils. Survey Time 30 April 1973

Nature of working of fields in 1972	Photoimage tone	Number of fields considered	Mean level of gray tone	Difference in levels of gray tone relative to bare fallow
Bare fallow	Gray	7	36-41	--
Deep loosening of soil in autumn at depth of 25-27 cm	Gray-light gray	30	39-41	3
Scuffling of stubble with cultivator-cutters to 8-12 cm	Light	35	43-48	7
Stubble of grain crops	Light, almost white	22	46-52	10

The plateau drops off in steep denudation scarps (chinky) toward the Kara-Bogaz-Gol; these features are clearly visible on space photographs. On the photograph a high percentage of the Ustyurt Plateau has a homogeneous gray photoimage tone. Gray-brown desert solonchak-like, takyr-solonetz-like, leached (elutriated) soils and soils with a high gypsum content are formed here under wormwood-Russian thistle, wormwood-biyurgunova and wormwood-bayalyna vegetation.

Using space photographs it is easy to see the difference between the soil cover of the Mangyshlakskoye and Krasnovodskoye Plateaus. North of the Kara-Bogaz-Gol, in the territory of the Mangyshlakskoye Plateau, on the basis of the gray and dark gray photoimage tones it was possible to interpret gray-brown desert solonetz-like and solonchak-like, frequently gravelly soils predominantly of a heavy mechanical composition (Table 27). A bright-light tone corresponds to depressions without external drainage with solonchaks. On the eroded sectors of plateaus there are exposed bedrocks: clays, limestones, gypsums. On the photograph these places can be detected from the serrated-striated photoimage pattern. These characteristics of the soil cover of the Mangyshlakskoye Plateau are especially clearly interpreted from a color space photograph taken from the "Soyuz-12." L. N. Kuleshov, et al. (1977) also examined the possibilities of interpretation of soils in the territory of the Mangyshlakskoye Peninsula.

The soil cover of the Krasnovodskoye Plateau is characterized by the widespread development of gray-brown sandy and sandy loam soils. Here it is common to encounter sectors of hilly and ridged, poorly consolidated and deflatable sands. Takyrs and solonchaks are formed in depressions. A photograph of the soil cover of this territory shows a mottled spotty-tongue-like pattern of a gray, light gray and light tone. Difficulties in interpretation of the soil cover from space photographs are attributable to the presence of cloud cover. We made a still more detailed interpretation of the soil cover in this territory from a photograph (scale 1:2,500,000) taken from the "Salyut-4" (Fig. 24, 24a).

We will also examine a photograph of the desert zone taken from the "Gemini" spaceship and characterizing the photoimage of the soil cover. The space photograph (Fig. 25) covers the territory of the Namib Desert adjacent to the coast of southwestern Africa. We used a soil map of Africa in its interpretation.

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On the basis of tone and type of photoimage the photograph is clearly subdivided into three major regions. The upper part of the photograph covers the southern part of the Damaraland Plateau and there are mountain red-brown soils of savannas and reddish-brown desertified savannas. The photoimage tone of these soils is gray or dark gray with a characteristic ridged-dislocated type of structure. The middle part of the photograph has a light tone of a uniform pattern typical for the image of gravelly-rocky soils of tropical deserts. The photograph shows a very sharp contrast between a sector of gravelly-rocky and sandy deserts. The sandy part of the Namib Desert on the photograph has a gray tone of the photoimage and a dune-ridge type of structure characteristic for deflatable and semiconsolidated sands. The space photograph shows that the extent of the sand ridges can attain even several hundreds of kilometers.

An investigation of the interpretability of the soil cover from space photographs of the desert zone indicated that due to the good exposure of the soil surface the effect of soil identification in this zone is high. On space photographs the soil cover of the desert zone is interpreted more precisely and more completely than for the steppe zone.

A space survey makes it possible to monitor the state of soils and their modification under the influence of irrigation and also identify areas of secondarily saline soils. On space photographs it is rather easy to determine irrigated lands of the semidesert and desert zones from the sharply differing coloration of moist irrigated and dry soils. In the future, using data on changes in the depth of soil and ground water, plans call for determining the times for the carrying out of irrigation and the quantity of water necessary for the cultivation of agricultural crops.

Using a space photograph (scale 1:1,500,000) taken from the "Salyut-1" after considerable enlargement it was possible to distinguish an irrigation system from the water intake to the water outlet (Sheyko, 1975). In part it was possible to see the main canal, along which a dark gray band with rounded (festooned) edges corresponds to sectors with the soil-ground water at a shallow depth.

A space photograph at a scale of 1:1,500,000, taken from an altitude of 300 km from the "Gemini-5" spaceship, clearly shows the fertile old irrigated lands of the Tigris and Euphrates valleys. The highly dissected folded limestone-marly chains of the Zagros Mountains adjoin them on the east. A marked periodic increase in the mass of water in the lower reaches of the Tigris results in floods and the development of a hydromorphous landscape with alluvial-swampy and solonchak-swampy soils. On a color photograph swampy areas have a dark blue color and diffuse, amebalike boundaries. The dessicated saline bottoms of lakes and swampy sectors are determined from the lighter color of the salt crust image on their surfaces.

A study of the natural wealth and proper use of river deltas in agricultural production is of great importance. River deltas, being some of the recent formations on our planet, make possible direct observation of the formation of the earth's present-day surface.

We determined the characteristic delta structure of alluvial irrigated soils from the next photograph, taken at a scale of 1:700,000 (Fig. 26). This space photograph covers a considerable part of the Nile delta and adjacent territories with soils of the subtropical deserts. Irrigated soils were represented by a dark gray tone, against whose general background it was easy to detect the meandering channel of the Nile River. The photoimage of the sandy and gravelly-rocky soils of the subtropical deserts surrounding the delta has a gray and light-gray tone with a characteristic complexly dendritic pattern -- the image of numerous dry wadis. For the territory of Ethiopia, using the photographs it is also possible to determine the soil-plant cover of the valleys and deltas with maximum detail.

On a space photograph of the territory of Central Asia, taken from the "Salyut-4" (scale 1:2,500,000), we interpreted the present-day delta of the Amudar'ya delta, and also with cartographic accuracy, amidst the sands, on the basis of the delta form and pattern of the photoimage of different tonality, it was possible to see several ancient deltas of this river (Fig. 27, 27a).

On existing soil maps there are no representations of soil areas of ancient deltas. With respect to genesis, the soil cover of these ancient delta territories (desert takyrlike soils, solonchaks) is sharply different from the genesis of the sands surrounding them. With respect to tone, pattern and image contrast on the photographs the sectors of the ancient deltas of the Amudar'ya are nonuniform and differ with respect to age of formation. This makes it possible to detect the age of formation of the soil cover of these territories.

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Fig. 26. Space photograph of territory of northeastern part of Africa (Nile delta). Scale 1:700,000. Survey made from spaceship "Gemini." Soils: 1) alluvial irrigated soils of delta (main canals are visible); 2) sandy soils of subtropical deserts; 3) pebbly-rocky soils of mountainous areas of subtropical deserts.

A space survey, in comparison with an aerial survey, is characterized by a rapidity in the collection of data for extensive regions of the earth. The period of revolution of different space vehicles around the earth is about 90-100 minutes. During a 24-hour period the Soviet system of the "Meteor" artificial earth satellite type is able to take photographs of half the earth. The television cameras of artificial earth satellites of the "ITOS-2" type daily transmit up to 140-150 images of the earth's surface. Computations made in the United States show that in a survey from space the entire territory of the country can be represented on 400 photographs. In order to carry out this work it is necessary to have about 17 days instead of 10 years of work with an ordinary aerial survey. The rapidity of obtaining space materials covering great areas and obtained at one survey time is of great importance for the comparative study of operation of irrigation and drainage systems for individual basins and as a whole for determining the nature of the soil cover of different natural landscapes, etc.

Fig. 27. Space photograph of the delta of the Amudar'ya. Survey from the "Salyut-4" in June 1975. Scale 1:2,500,000. 1) modern delta of the Amudar'ya; 2) ancient delta of the Amudar'ya.

Thus, space photographs can be used in determining the resources of irrigated and saline lands, for clarifying the nature of moistening and change in soils under the influence of irrigation measures, and for determining the areas of secondary salinization.

Agricultural Interpretation of Space Photographs

Space photographs can be successfully used for ascertaining the use of soils, clarifying the condition of agricultural crops and determining their crop yield.

On black-and-white space photographs of the steppe zone of Kazakhstan and Altayskiy Kray taken from the "Salyut-1", on the basis of the different image tone and structure there was reliable determination of plantings of

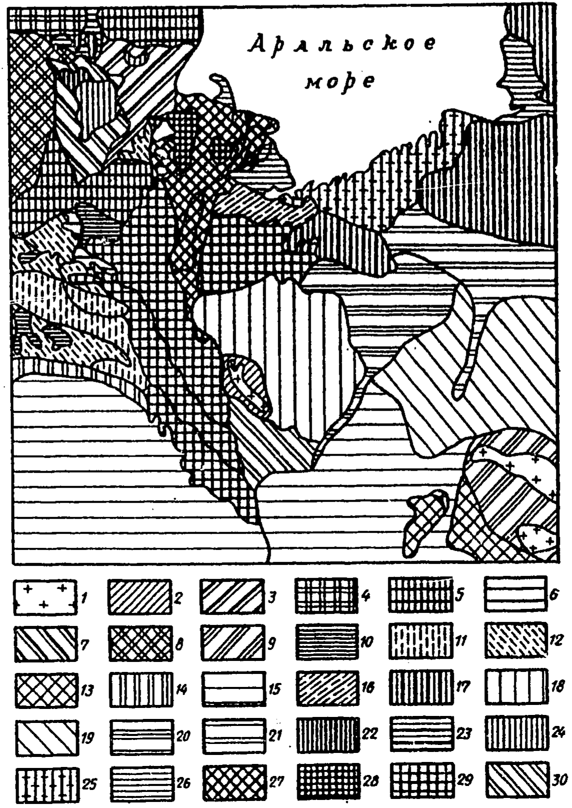


Fig. 27a. Soil cover interpretation of Amudar'ya delta region from space photo from "Salyut-4" in June 1975. Soils: 1) gray-brown typical and solonchak-like gravelly soils; 2) gray-brown typical clayey loam and light clayey loam soils; 3) gray-brown solonetz-like soils; 4) gray-brown solonchak-like soils; 5) gray-brown typical and solonchak-like soils; 5) gray-brown typical and solonchak-like soils; 6) gray-brown solonetz-like and solonchak-like soils; 7) gray-brown solonetz-like soils and solonchaks; 8) gray-brown solonchak-like soils and solonchaks; 9) gray-brown typical and solonetz-like soils; 10) desert takyr-like soils; 11) desert takyr-like soils and solonchaks; 12) desert takyr-like solonchak-like soils, takyrs and solonchaks; 13) desert takyr-like solonchak-like soils and solonchaks; 14) sands on Paleogene and more ancient rocks and solonchaks; 15) sands on Pliocene ancient alluvial deposits; 16) sands on Pliocene Quaternary alluvial deposits of Amudar'ya and desert takyr-like solonchak-like soils; 17) sands and desert takyr-like soils; 18) sands on Paleogene and more ancient rocks and desert takyr-like soils and takyrs; 20) desert takyr-like soils, takyrs and solonchaks; 21) desert takyr-like soils, takyrs, sands and solonchaks; 22) desert takyr-like solonchak-like soils and solonchaks; 23) takyr solonchak-like soils and solonchaks; 24) solonchaks; 25) solonchaks and sands; 26) marshy solonchaks; 27) meadow and swampy saline and nonsaline floodplain soils; 28) swampy saline and nonsaline floodplain soils; 28) swampy saline and nonsaline floodplain soils; 29) old irrigated meadow and old irrigated saline soils; 30) old irrigated meadow saline soils and solonchaks.

agricultural crops (Table 28). The reliability of interpretation for different crops was different. For example, fields with perennial grasses are interpreted reliably from the dark gray, almost black tone, the rectangular form of the units with distinct boundaries and a homogeneous pattern. Grains (wheat, barley, oats) have a similar gray image tone. Fields with grain crops are clearly interpreted on a plain and somewhat less clearly in the foothill zone, where with respect to phototone they merge with mountain pastures. Fields with corn show up in a dark gray tone but are not always interpreted because with respect to photoimage they are close to pastures. Fallow fields, having a light gray tone, of a homogeneous or spotty structure, are reliably interpreted, but with respect to tone coincide with the generalized photoimage of solonetz soils.

In carrying out our investigations from a space photograph of the territory of Northwestern Kazakhstan with dark chestnut calcareous and meadow-chestnut calcareous soils it was possible to determine the nature of agricultural working of the fields. The survey was carried out on 30 April 1973 prior to the carrying out of spring field work over this territory. Accordingly, the different working of the soils in 1972 was reflected on the photographs. Ninety-four fields were subjected to visual-instrumental interpretation using a "Kvantimet-720" image analyzer and subjected to field checking.

On the basis of the different photoimage tone (Table 29) for the soil surface it was possible to have reliable discrimination of fields in which there was bare fallow during 1972. These fields accumulated the greatest quantity of moisture during the summer-autumn period of 1972 and the early spring period of 1973 and on the photographs appeared in a gray tone (average level of the gray tone 36-41). A light gray tone (39-44) was characteristic of fields in which during the autumn there had been deep loosening of the soil to 25-27 cm. During the autumn and early spring periods these fields also accumulated considerable quantities of moisture, but less than in fallow sectors.

A light tone (43-48) corresponds to fields in which in the autumn of 1972 there was scuffling by cultivators-cutters to a depth of 8-12 cm. Finally, the lightest image (46-52) on space photographs was characteristic of space photographs of unworked fields in which the stubble of grain crops remained in autumn. In an analysis of the photoimage of the two latter fields it is necessary to take into account not only the nature of the moistening, but also the state of the soil surface (rough, smooth) and especially the presence of stubble on its surface. On space photographs at a scale 1:2,500,000-1:1,000,000 taken from the "Salyut-4," on the basis of different tone we reliably determined plantings of agricultural crops. In the territory of the Saratovskoye Povolzh'ye, where three farms were subjected to field checking and 146 fields were taken into account, from a space photograph for the summer survey period (June) it was possible to discriminate the following sown areas and land uses. A light, almost white photoimage tone was characteristic of infrequent fields with plantings of winter rye and winter wheat; light gray tone corresponded to fields with melon crops and fields with three-level plowing of the soil; gray tone corresponded to spring wheat, barley, oats and grazing sectors; dark gray tone corresponded to corn, sunflower and alfalfa; on the photographs an almost black tone corresponded to irrigated alfalfa and forested sectors.

On space photographs of the steppe zone of the Ukraine (Khersonskaya Oblast), where two farms were field checked and 137 fields were taken into account, the following crops were determined for the summer survey period. A light, light gray tone corresponded to numerous fields of winter wheat; a gray tone corresponded to spring crops (barley, oats) and sectors of pasture; a dark gray tone corresponded to corn, sunflower, alfalfa and sectors of clean fallow; fields with irrigated alfalfa corresponded to an almost black tone of the photoimage.

A comparative analysis of the photoimage of agricultural crops on space photographs (same survey season) of these two soil-geographic regions of the steppe zone of the European territory of the country indicated their similarity. With the availability of a small number of key sectors this makes possible a routine and reliable determination and prediction of the types and state of development of the main agricultural crops from space photographs for a definite soil-agricultural zone.

In two space polygons in the United States, located in South Dakota and Arizona, the problems involved in the interpretation of sown areas and their condition is the emphasis of a scientific program in the field of agriculture. For example, in the South Dakota polygon the materials from joint surface investigations, aerial survey data and data obtained from space satellites or orbital stations (of the ERTS and "Skylab" types) have been used for the following purposes: a) estimation of the yield of agricultural crops; b) estimation of the productivity of pastures for domestic cattle; c) establishing a relationship between soil fertility, moisture content and local topography.

On one of the space photographs of the Imperial valley in California (in the United States), taken during flight of the "Apollo-9" spaceship on 12 March 1969 from an altitude of 240 km for the purpose of studying resources and including for the identification of soils and agricultural land use in the territory of the United States and Mexico, the agricultural irrigated fields have a bright red color on the photograph in the United States, but similar territories in Mexico with a high percentage of idle and saline lands with a reddish-greenish-dark blue color.

Agricultural fields of the irrigated Imperial valley show up most clearly and graphically. Depending on the type of agricultural crops the fields show up in a red color (from light orange-red to blue-red). Sugarbeet and alfalfa fields not yet harvested at the time of the survey appear in a bright red color. Groves of citrus crops are characterized by a darker red "muffled" tone. A light blue and bluish-green hue corresponds to fields of harvested cotton. On the photograph, in an irrigated zone amidst the agricultural fields, it is easy to see dams, water bodies, main and secondary irrigation canals.

One of the important characteristics of use of space materials for agricultural purposes is the possibility of a rapid repetition of the survey. This problem is successfully solved by employing photoelectronic space methods for collecting information on soil-agricultural phenomena. The routineness of space information is important for judging rapidly developing dynamic processes transpiring at the earth's surface. For the first time by means of repeated surveys from space it was possible to judge simultaneously the nature of snow melting over enormous areas of the earth and the development of the processes of erosion and distribution of seasonally and repetitively saline soils.

The routine data regularly received from artificial earth satellites are especially necessary for determining the condition of agricultural fields, for checking plant diseases and the distribution of pests afflicting agricultural crops, as well as for determining the areas of dead crops and field weediness.

The availability of routine space information on the phases of development and condition of agricultural crops will make it possible to predict their yield and make a more precise determination of the calendar plan for carrying out agricultural work.

American specialists feel that due to the differences in the image of plantings of different crops (soy beans, corn, winter wheat, rice, cotton, etc.) ERTS photographs have potentialities for routine computation of the yield. For this purpose a semiautomated system for the processing of space photographs is being developed for the solution of agricultural problems.

Chapter 6

CHARACTERISTICS OF INTERPRETATION OF SOILS AND SOWN CROPS FROM MULTIZONAL AERIAL PHOTOGRAPHS

The use of multizonal photographs has now been initiated in the search for an increase in the information capacity of aerial and space materials for the study of natural resources, including the soil cover and agricultural crops. This type of survey is based on obtaining an image of the soil cover and agricultural crops simultaneously in several narrow spectral zones. As a result, for soil and agricultural interpretation as interpretation criteria it is possible to use the differences in spectral brightness of different soils and agricultural crops.

In the visual-instrumental interpretation of multizonal photographs use was made of the following elements of the image of soils and sown crops: 1) spectral (difference in image tone in different spectral zones); 2) textural (distribution of tonal variations within the limits of one zone); 3) landscape (relationship between soil characteristics and the environment). A study and registry of these image elements, especially the first two, will make it possible in the future to approach the machine processing of photographs.

It is possible to obtain images by detectors having different spectral response in the optical, thermal and radio ranges of the electromagnetic spectrum. However, during recent years a multizonal survey in the optical range in the visible and near-IR spectral regions has been developed to the greatest degree.

In our country in the mid-1930's the studies of V. A. Faas (1936) laid the basis for a multizonal survey. Later fundamental investigations in the spectral classification of different natural features, including soils, were made by Ye. L. Krinov (1947). An important stage in the development of a multizonal survey was the work of A. N. Iordanskiy (1967) for creating a series of spectrozonal films. A considerable influence on the development of a multizonal survey of the earth's surface was exerted by the work of the Aerospace Methods Laboratory of the Geography Faculty Moscow State University, where the first special multiobjective survey camera was constructed in the late 1950's.

Multizonal scanner systems appeared later. In 1973 a multispectral scanning system (MSSS) and a digital videorecording unit were employed in the study of natural resources (Khodarev, Avanesov, et al., 1974). The "Fotoskaner-4" was used in the surveying of geological features; it operates in the ultraviolet, visible and infrared spectral zones (Apostolov, Selivanov, 1974).

The use of multizonal materials is affording additional new possibilities for a more complete and objective interpretation of the soil cover and plantings of agricultural crops.

Various studies (Andronikov, 1976, 1979; Andronikov, Sinitsina, Shershukova, 1975, 1977; Afanas'yev, et al., 1978; Vinogradov, 1976; Vinogradov, Glushko, 1976; Garelik, et al., 1976; Zonn, 1977; Knizhnikov, Kravtsova, 1976; Labutina, Chechneva, 1976; Miroshnichenko, et al., 1977; Tolchel'nikov, Chukov, 1977) examine the problems involved in the use of multizonal photographs for the study of natural resources, including for the identification of soils and agricultural crops.

As an interpretation criterion for multizonal images in a microphotometric analysis use is made of both the absolute optical density and the difference in optical densities, measured at the boundary of two adjacent features. In this case the basis for a successful interpretation of soil-agricultural features is the different degree of expression of their boundary contrast on photographs taken in different zones of the electromagnetic spectrum. The absence or poor (unreliable) presence of a boundary contrast on the films of one zone and its appearance on films of other spectral zones considerably increase the reliability of interpretation of soils and agricultural crops, including such an important index as yield.

The possibility of determining agricultural crops and soils was compared for the territory of the United States using IR color and multizonal black-and-white films. The correct identification of alfalfa fields from color infrared films was 70%, when black-and-white films were used -- 40%; for barley fields the corresponding values were 69 and 62%; for sugarbeet fields -- 70 and 90%; for plowed fields -- 64 and 82%; for saline soils (solonchaks) -- 67 and 89% (Leamer, Weber, Wiegand, 1975).

A multizonal aerial survey of the soil cover was made in southeastern England in four spectral ranges -- from blue-green (0.4-0.5 m) to IR (0.7-0.9 μm) at a scale of 1:15,000. Photographs in the red zone surpassed photographs taken in the blue and green spectral zones with respect to information yield (period May through July). The July photographs contain more information than June photographs, but the best results for the study of soils were obtained from aerial photographs taken in March-April (Evans, 1975).

In our investigations for study of the possibilities of interpretation of soils and agricultural crops we made use of multizonal photographic aerial photographs for the territory of the steppe and dry steppe zones and multispectral aerial photographs for the desert zone. The "Kvantimet-720" image analyzer was used in an analysis of the photographs and films and quantitative measurements of the level of the gray tone of the photoimage of the soil cover, agricultural crops and virginland vegetation.

Interpretation of Multizonal Aerial Photographs of Steppe Zone

The territory of an experimental sector of the Central Russian Highland was a reference area for the steppe zone in which the testing of aerospace methods for the study of soils and agricultural crops was carried out. This sector was selected as an experimental area for study of natural and anthropogenic geosystems of the central part of the wooded steppe on the Russian plain (Gerasimov, Grin, 1976).

At the present time all the lands convenient for agriculture in this zone are cultivated (cultivated area more than 70%) and the natural vegetation of the meadow steppe has been preserved only in individual sectors with adjacent forests.

The relief of the investigated territory of the Central Russian Highland is erosional. The water divides have a slightly convex surface. The ravines are sodded. The soil-forming rocks are represented by calcareous loess-like pulverized clayey loams. The soil cover consists of thick chernozems which can be assigned to typical and leached subtypes and meadow-chernozem soils. Typical and leached chernozems have the widest occurrence on the water divide plateaus and slopes and replace one another at close distances. Calcareous excavated chernozems -- hillocks at the mouth of marmot burrows -- occur widely. Podzolized chernozems are rarely encountered and are developed in the upper part of gullies and ravines where the soils receive additional moistening. Meadow-chernozem soils are associated with microdepressions and the bottoms of steppe ravines. Alluvial meadow, moist meadow and meadow-swampy soils are formed on the floodplain of the Seym River.

In 1973 a multizonal aerial survey of this territory was carried out in the second half of September when grain fields were harvested and sprouts of winter wheat appeared and a great number of fields were free of sown crops. Among the different survey zones of the electromagnetic spectrum, in the interpretation of 1973 we used the green zone with sensitivity maxima at (520 nm), yellow-green (560 nm), red-orange (610 nm) and near-IR (840 nm). Three zones were selected for subsequent analysis: green, red, IR, having the greatest contrasts with one another in the image of soils and sown crops.

Data from visual-instrumental interpretation of the soil cover, principal agricultural crops and virginland vegetation from multizonal photographs (Fig. 28, A, B, C) are given in Table 30.

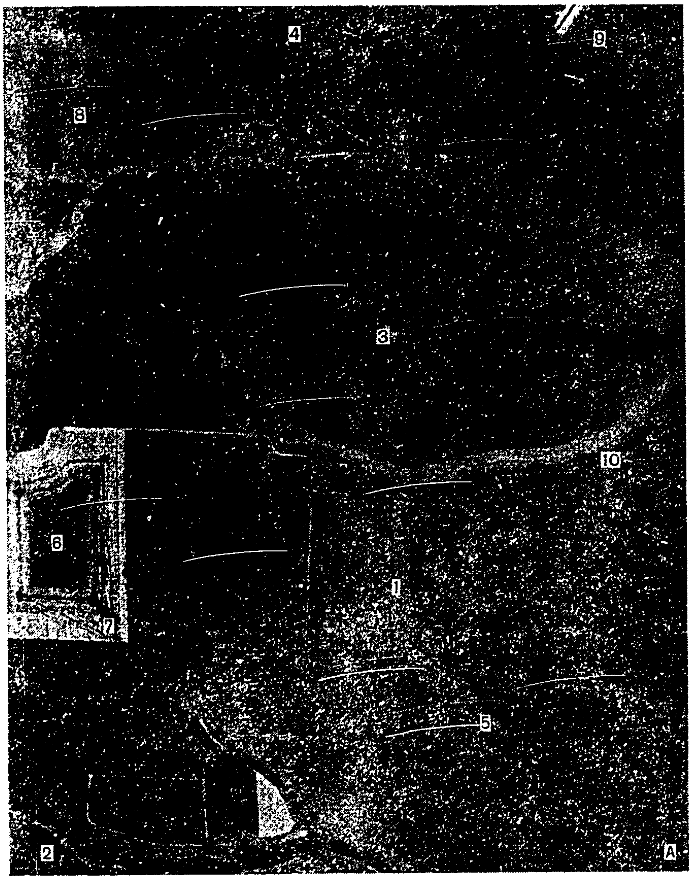
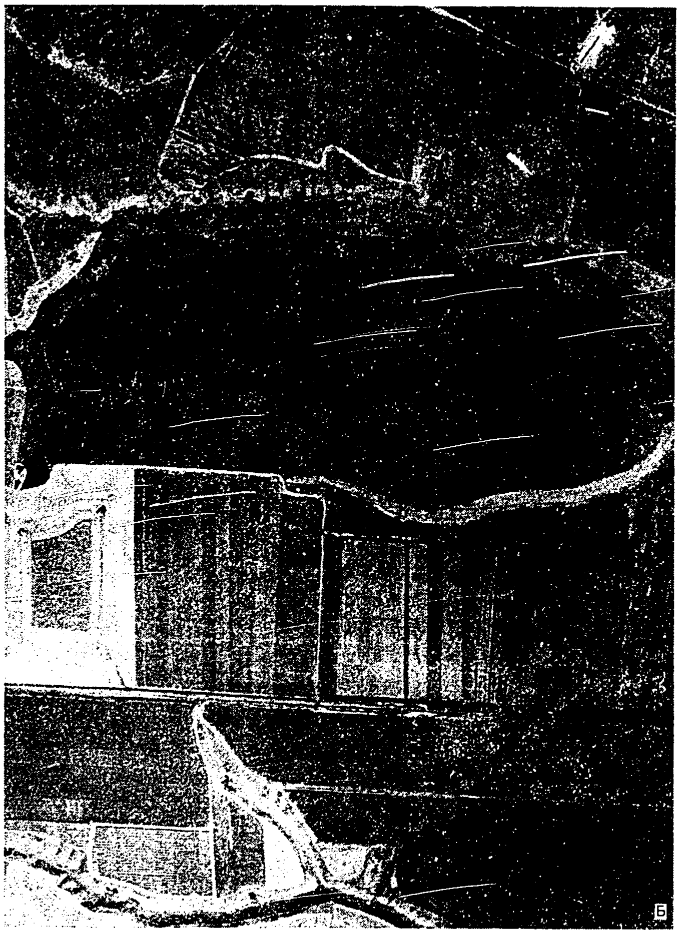


Fig. 28. Photoimage of soil cover and agricultural crops on multizonal photographs of experimental sector of steppe zone. Early autumn survey period. Spectral zones: A) green; B) red; C) IR. 1) fall plowing of soil (typical, leached and excavated calcareous chernozems on watersheds and meadow-chernozem soils in longitudinal troughs); 2) stubble of grain crops; 3) winter wheat prior to appearance of sprouts (typical, leached and excavated calcareous chernozems on watershed, weakly eroded on slopes and meadow-chernozem soils in troughs); 4) winter rye — sprouts (typical, leached and excavated calcareous chernozems on watershed, slightly eroded on slopes and meadow-chernozem soils in longitudinal troughs); 5) sugarbeets (before harvesting) (typical, leached and excavated calcareous chernozems on watersheds and meadow-chernozem soils in swales); 6) corn (harvest time); 7) corn (stubble); 8) virginland vegetation; 9) perennial grasses; 10) ravines (meadow-chernozem soils).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During the autumn period a number of fields are plowed and the soil surface shows directly on the aerial photographs. In these fields, from photographs in the green and red zones, with an adequate degree of assurance it is possible to interpret typical and leached chernozems and calcareous material excavated from meadow-chernozem soils with a sufficient degree of reliability in the green and red zones. These cannot be interpreted in the IR zone (840 nm). In this zone the difference in the level of the gray tone is virtually equal to zero.

Fields with the stubble of grain crops are reliably discriminated from freshly plowed fields with a direct image of typical, leached and calcareous excavated soils in all zones, but especially the red. Whereas fields with winter crops in the sprouting phase also have a good boundary contrast in all zones, except for the IR, sugarbeet fields in the green and red zones differ slightly with respect to the level of the gray tone and show up very sharply from an almost white tone in the IR zone. The interpretation of meadow-chernozem soils formed in microdepressions through plantings of sugarbeets was possible from photographs sensitive to the green spectral zone. Against the image background of winter crops (sprouting phase) meadow-chernozem soils in depressions were successfully interpreted from photographs in the green and also in the red spectral zones.

On the floodplains of steppe rivers on the basis of the image of meadow and meadow-swampy vegetation in all spectral zones it was possible to interpret alluvial meadow and meadow-swampy soils.

The interpretability of agricultural crops (difference in levels of gray tone of individual fields) is different for different spectral zones. The sharpest difference between winter crops (sprouts) and sugar beets can be seen in the IR zone (41-47 units versus 3-10 in the remaining spectral zones). This pattern, but with a lesser contrast, is characteristic for fields of corn, millet and perennial grasses.

The photoimage of winter crops (sprouts) is characterized by a gray image tone in the red and green spectral zones and an almost black tone not differing from the image of plowed soils in the IR zone.

Sectors of virginland vegetation (virgin steppe) were reliably determined on photographs in the red zone on the basis of a light gray tone, whereas the steppe, after hay mowing, is characterized by an almost white tone (similar to the image of sugarbeet fields) in the IR zone of the electromagnetic spectrum.

In 1974 a multizonal aerial survey was carried out in the late autumn period -- in mid-October. This is the time of maximum plowing of the fields and development of winter crops (tillering phase). Data from a visual-instrumental interpretation of the soil cover, agricultural crops and virginland vegetation are given in Table 31. In 1974 a survey was made in four spectral zones: green (520 nm), red (610 and 690 nm) and IR (840 nm). The red zone photographs had a uniform image and the zone 690 nm remained for analysis.

The surface of plowed typical and leached chernozems with small variations (be these fields with fields of grains or cultivated crops) shows up in a dark gray tone in the IR and in a gray tone in the red spectral zone. On photographs in the red, and to a lesser degree in the green zone, it is possible to see a fine "point" spottiness of a light gray tone which is associated with the photoimage of excavated calcareous soils. Another type of fine spottiness of an almost black (dark gray) tone is characteristic for the image of meadow-chernozem soils in microdepressions. Such spottiness does not appear on photographs in the IR zone. In addition, on the basis of a light gray image tone on IR photographs it is possible to interpret the appearance of weeds in fields. Whereas in this zone the difference in the level of the gray tone between fields with and without weeds is 7-11, in the red zone it is 1-2 and in the green zone is 2-6.

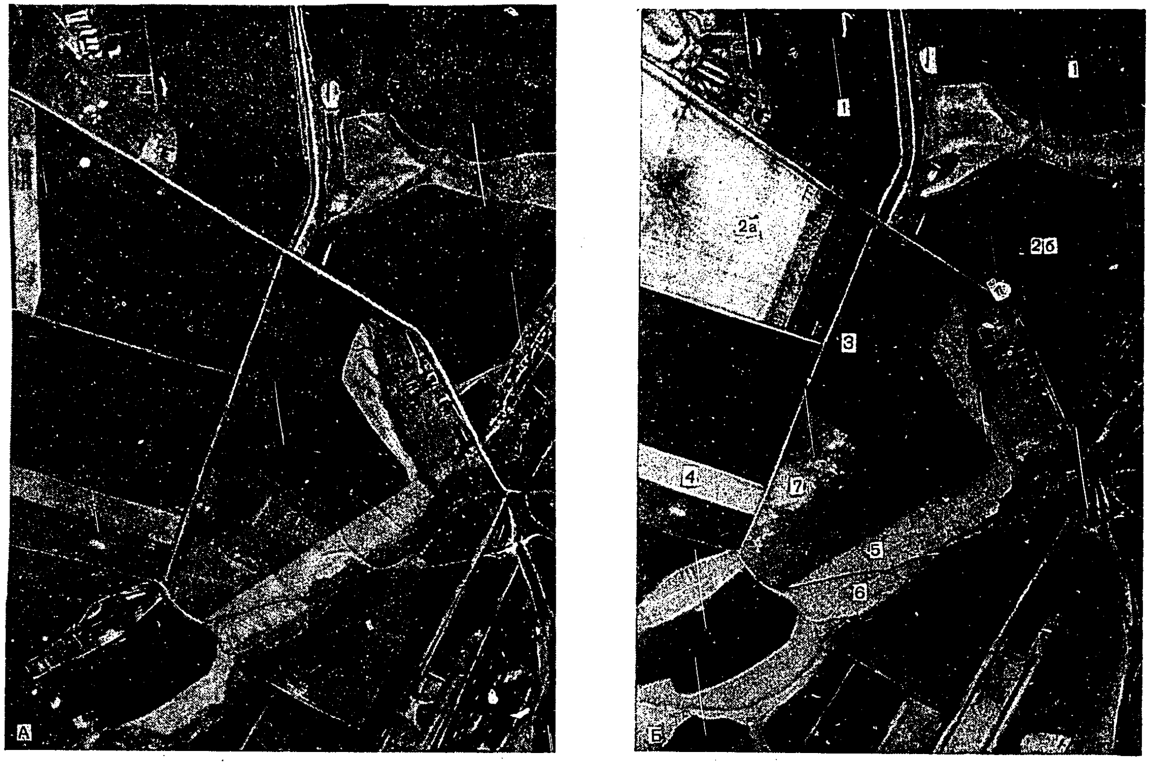

Fig. 29. Photoimage of soil cover and agricultural crops on multizonal photographs of experimental sector of steppe zone. Autumn survey period. Spectral zones: A) red; B) IR. 1) fall-plowed fields (typical, leached and excavated calcareous chernozems on watersheds, slightly eroded chernozems on slopes and meadow-chernozem soils in longitudinal troughs and swales); 2) winter wheat (tillering phase), sown on: a) bare fallow (harvest in next year 40 centners/hectare); b) occupied fallow (peas) (harvest next year 25 centners/hectare); 3) winter rye (tillering phase); 4) fodder beets (harvest time); 5) perennial grasses (regrassing of eroded slopes); 6) meadow-steppe vegetation in ravines (meadow-chernozem soils); 7) weeds in fields.

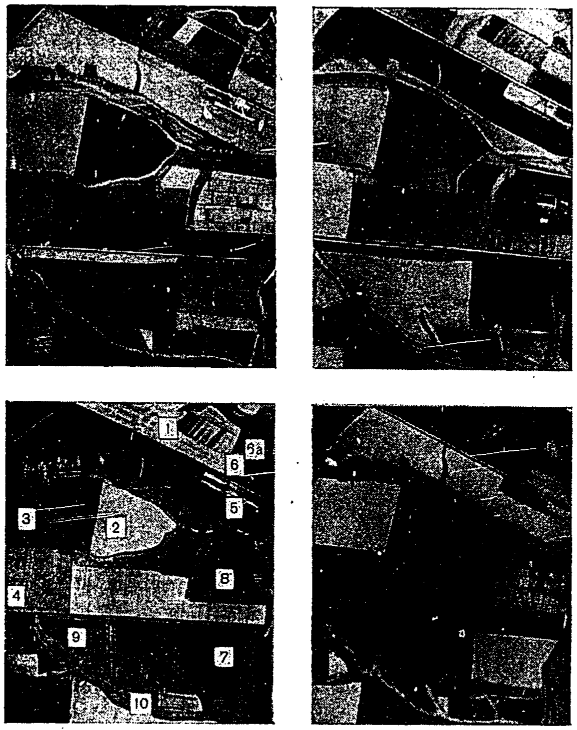

Fig. 30. Change in tone and contrast of photoimage of agricultural crops on summer multizonal aerial photographs in dependence on development phase and spectral zone of survey (one and same sector of steppe zone photographed during vegetative development of plantings with difference in survey time of one month). Survey time: at top -- beginning of summer; at bottom -- mid-summer. Spectral zones: at left -- red, at right -- IR. 1) stubble of winter wheat harvested in mid-summer; 2) barley; 3) buckwheat; 4) peas; 5) sugarbeets; 6) fodder beets; 6a) fodder beets with weeds; 7) corn (at the beginning of summer meadow-chernozem soils in longitudinal troughs and swales can be seen through its photoimage); 8) potatoes; 9) perennial grasses; -- sweetclover with red clover (at top); after a month the grasses are mown and the soil is plowed (at bottom); 10) meadow-steppe vegetation in ravines (meadow-chernozem soils).

Fig. 31. Aerial photograph of ancient runoff trough of experimental sector of dry steppe zone.

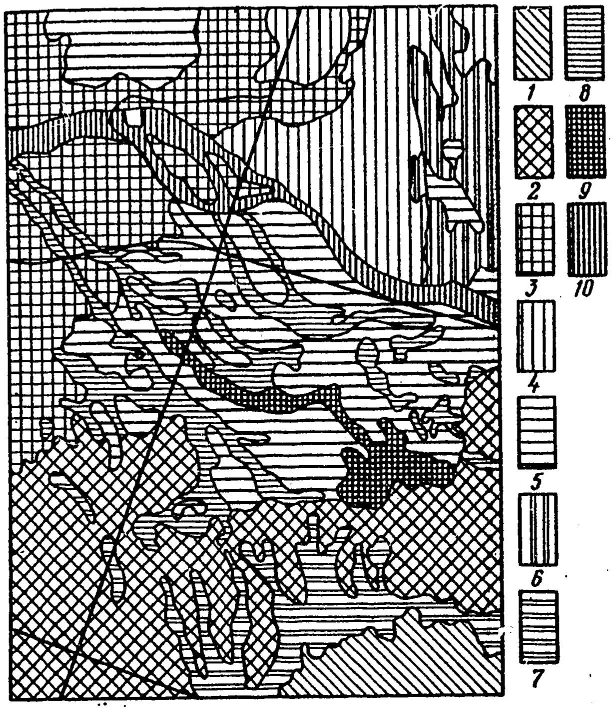

Fig. 31a. Soil map of ancient runoff trough of experimental sector of dry steppe zone. Soils: 1) dark chestnut solonetz-like clayey loam soils of medium thickness and deep steppe solonetz soils (50%); 2) dark chestnut slightly solonetz-like soils, meadow-chestnut solonetz-like heavy clayey loam soils and deep steppe solonetz soils (10-20%); 3) dark chestnut highly solonetz-like soils, meadow-chestnut highly solonetz-like soils and fine meadow-steppe solonetz solonchak-like clayey loam soils (20%); 4) fine clayey steppe solonetz soils with participation of dark chestnut solonetz-like soils and meadow-chestnut solonetz-like soils; 5) fine solonchak-like clayey loam meadow-steppe solonetz soils with participation of meadow-chestnut solonetz-like soils; 6) meadow-chestnut solonetz-like soils and meadow-steppe clayey loam solonetz soils (20%); 7) solonetz-like clayey loam meadow-chestnut soils; 8) highly solonetz-like clayey loam meadow-chestnut soils; 9) solonetz-like clayey loam meadow soils; 10) compact clayey loam meadow soils.

A study of the photographs taken in different spectral zones indicated that using them it is possible to discriminate plantings of winter wheat (tillering phase), sown on bare and occupied fallow; the greatest difference can be seen in the IR zone (Fig. 29, A,B). In the IR zone an almost white tone corresponded to unharvested fields of fodder beets. Differences in the photoimage of meadow-steppe vegetation of steppe ravines with meadow-chernozem soils and meadow-swampy vegetation with alluvial-meadow and meadow-swampy soils are interpreted better from photographs in the red zone and considerably poorer in the IR spectral zone.

One of the principal results of carrying out a multizonal survey in late autumn (October) is the possibility of: a) a more detailed analysis of the soil cover; b) determination of the level of development of winter crops and prediction of their yield for the next year.

In 1975 a multizonal aerial survey was carried out twice: early in the summer (5 June) and a month later (9 July). This was a period of intensive growth and development of agricultural crops and the first half of July was the beginning of harvesting of winter crops. As indicated by an analysis of summer photographs, at this time there is virtually no open surface of the soil cover and soil interpretation is accomplished through the direct image of agricultural crops. The interpretability of soils in different spectral zones and through different crops is different (Table 32).

On the June photographs in the green and red zones through the photoimage of sugarbeets, having a light gray tone, it was easy to interpret meadow-chernozem soils (Fig. 30). They show up as fine dark dots (in the formation of soils in swales) and dark striations (in the case of formation of meadow-chernozem soils in longitudinal troughs). Similarly, on June photographs it is possible to interpret meadow-chernozem soils successfully amidst typical and leached chernozems through the direct photoimage of fields of corn and potatoes. In the IR zone they are not interpreted or are determined with greater difficulty. Accordingly, during early summer through the photoimage of cultivated crops against the background of chernozems there can be reliable interpretation of meadow-chernozem soils in the red and green spectral zones. On July photographs this possibility is lacking in all spectral zones. By mid-summer cultivated crops are well-developed and completely mask the soils.

In addition, an analysis of the July photographs indicated that meadow-chernozem soils, formed in swales and longitudinal troughs, are interpreted on photographs taken in the green and red spectral zones through a planting of spring wheat with an undersowing of clover and especially through a planting of vetch. In a field occupied by vetch it is easy to see the dotted-striated soil cover structure. The data in Table 33 show that the greatest differences between chernozems and most agricultural crops are observed in the IR zone.

On the June photographs (see Table 32) from the photoimage of winter wheat in the green and IR spectral zones it was possible to determine the difference in the yield of wheat sown on bare fallow — 40 centners/hectare and wheat sown on occupied fallow (peas) -- 25 centners/hectare. The difference in the levels of gray tone between wheat with yields of 40 and 25 centners was 10-15 units. In the red zone it could virtually not be discerned at all. At the same time, it was established that on the photoimage on multizonal aerial photographs obtained in all three spectral zones during this month plantings of winter wheat with a high yield are similar to sectors of meadow-steppe vegetation, sown perennial grasses, as well as fields of spring wheat and barley with an undersowing of perennial grasses.

The investigations indicated that for the reliable identification of agricultural crops a change in their photoimage in different spectral zones in dependence on survey time is of great importance. For example, spring wheat and barley from June to July change tone on photographs in the red zone from dark gray, almost black, to light gray, almost white, whereas cultivated crops (sugarbeets and corn) vary from light gray to dark gray. However, images of meadow-steppe and meadow-swampy vegetation, and also forests, do not experience sharp changes in tonality on photographs from June and July surveys. For mid-summer (July) we made a comparison of the photoimage of the surface of the analyzed steppe sector, obtained synchronously on multizonal aerial photographs and a space photograph. A comparative analysis of the photoimage indicated that with respect to tone agricultural crops, forest and soils on a space photograph are similar to the same features on an aerial photograph taken in the red zone. Accordingly, the interpreted aerial photographs for one and the same survey time (in the limits up to two weeks) and photographs from space can serve as a "key" for the interpretation of space materials.

In conclusion we will give a summarized table-key for the interpretation of the principal soils (Table 34) in an experimental sector of the steppe zone which we compiled on the basis of a soil interpretation of multizonal aerial and space photographs. In working up this table-key we used data on soil-forming factors (relief, vegetation, soil-forming material), physical and chemical properties of soils, exerting an influence on their reflectivity, and have indicated the soil interpretation criteria.

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Interpretation of Multizonal Aerial Photographs of Dry Steppe Zone

A study of the soil cover and plantings of agricultural crops of the dry steppe zone from aerospace photographs was made in the territory of one of the experimental sectors in Northwestern Kazakhstan.

In physiographic respects the analyzed territory covers the southern part of the West Siberian Lowland — the Turgayskaya "tableland" country. The northern part is situated within the limits of an undulating sandy plain and the southern part is situated within the limits of an extensive plateau. In geobotanical respects this zone is a dry steppe with a predominance of feathergrass-sheep's fescue-mixed grasses, feathergrass-sheep's fescue-wormwood associations on dark chestnut soils and sheep's fescue-wormwood-goldilocks associations on solonetz soils.

The territory has a lowland relief. In geomorphological respects it is possible to discriminate northern, central and southern parts in the considered region. The northern part is a slightly undulating sandy plain, complicated by numerous mesodepressions, frequently occupied by bitter-saline lakes. The lakes are slightly incised, with flat bottoms. The expanses between the lakes are flat, sometimes slightly convex water divides with gentle slopes (1-3°) of different length and exposure.

The soil-forming rocks here are unconsolidated sandy and sandy loam Quaternary deposits underlain by a Paleogene sandy-pebbly stratum. The soil cover of the northern part of the considered territory is represented by dark chestnut sandy loam soils on the water divides, meadow-chestnut soils in depressions and small contours of solonchaks around bitter-salt lakes. Due to the light mechanical composition most of the lands in this part of the territory are not plowed and constitute a sheep's fescue-feathergrass-crested wheatgrass idle land or a virgin land with sheep's fescue-feathergrass-mixed grass and feathergrass-sheep's fescue-wormwood associations.

The central part of the lands of the experimental sector is an ancient runoff depression. This is a slightly undulating plain complicated by numerous forms of meso- and microrelief in the form of microdepressions, remanent hills, ridges, modern runoff troughs with intermittent watercourses. The soil-forming rocks here are represented by saline clayey loams, Tertiary variegated saline clays, in which the presence of microcrystalline gypsum is discovered beginning at a depth of 60-80 cm.

Aleuritic rocks participate in soil formation in individidual remanent hills. In the soil cover here there is widespread occurrence of solonetz, chestnut and meadow-chestnut solonetz-like soils (Figures 31, 31a).

The southern part of the territory occupies an extensive plateau. In its central lowland part there is extensive development of flat microdepressions and microhills of zoogenic origin — hillocks formed at the mouth of marmot burrows, creating a microcomplexity of the steppe surface. The soil-forming rocks are covering calcareous heavy clayey loams underlain by marine Paleogene deposits in the form of yellow-brown or reddish clays. The soil cover is very homogeneous and is represented by dark chestnut and dark chestnut calcareous excavated soils (marmot hillocks) on the plateau and calcareous meadow-chestnut soils in microdepressions (Figures 32, 32a). This territory is the principal cultivated land resource of the farm. Among the agricultural crops here there is a predominance of plantings of spring wheat and barley. In the central part a high percentage of the cultivated land is occupied by plantings of perennial grasses (crested wheatgrass).

In 1973 a multizonal aerial survey was carried out in the green (520 nm), red-orange (610 nm), IR (840 nm) spectral zones at the end of July, 60-70 days after the sowing of grain crops -- spring wheat and barley. On the territory of the plateau on dark chestnut calcareous and meadow-chestnut calcareous soils these crops form a dense cover and cover the soil surface. In this case the interpretation is made through the photoimage of the agricultural crops.

On the territory of the plateau through the photoimage of spring wheat and barley in the red spectral zone there is reliable discrimination of dark chestnut and meadow-chestnut soils; in the green and infrared zones they differ slightly (Table 35). Dark chestnut calcareous excavated soils (marmot hillocks) are not masked by plantings of grains; in the green and especially in the red zone they have a bright-light tone (50-62); these soils are not interpreted on photographs in the IR zone.

On the photograph the fields occupied by spring wheat and barley have a different tonality, well expressed in the red and IR zones and poorly expressed in the green spectral zone. These differences in overall tonality are attributable to a nonidentical yield of spring wheat and barley.

Now we will examine a sector of the territory of an ancient runoff trough with a varied complex soil cover. The analysis shows that in the red zone through fields of spring wheat there is clear interpretation of dark chestnut solonetz-like soils, meadow-chestnut solonetz-like and meadow solonetz-like soils. Steppe and meadow-steppe solonetz soils have similar photoimages, but differ clearly with respect to their position in the relief. In the green zone such a field has a less contrasting photoimage. In the IR zone a field of winter wheat with a complex soil cover has very weak contrasts. For example, whereas in the red zone the difference in the level of the gray tone between meadow-chestnut soils and solonetz soils attains 24 units, in the IR zone this difference is 3. An exception is the meadow solonetz-like soil, which is reliably interpreted in the IR zone from the light tone of the photoimage.

From the photoimage of corn in the IR zone it is easy to see the difference between fields with a different sowing time. In the red zone it is traced with difficulty and in the green zone is absent. For example, whereas

Fig. 32. Aerial photograph of sector of plateau of dry steppe zone.

the difference in the level of the gray tone between early and late plantings of corn sown on dark chestnut sandy loam and light clayey loam soils in the green zone is virtually equal to zero, and in the red zone -- 3-5, in the IR zone it is 8-10 units.

The interpretation of the soil cover through early and late plantings of corn was accomplished most successfully from photographs in the red spectral zone. In this zone through the photoimage of corn it was possible to determine dark chestnut sandy loam and light clayey loam arenaceous, meadow-chestnut light clayey loam and meadow-steppe solonetz soils. In the green and IR zones the photoimage of these soils has a weak contrast (Fig. 33).

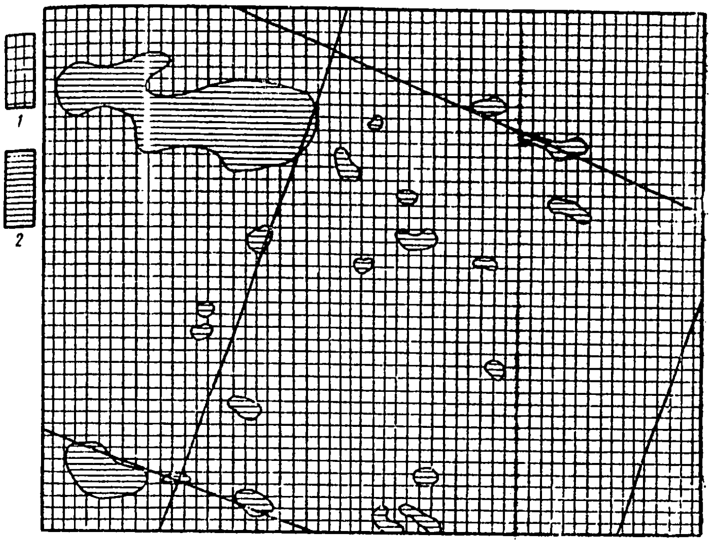

Fig. 32a. Soil map of sector of plateau in dry steppe zone. Soils: 1) dark chestnut calcareous, medium-thickness, clayey and dark chestnut excavated (hillocks at mouths of marmot burrows -- white dots on photograph) soils; 2) meadow-chestnut calcareous clayey soils.

For example, the difference in the level of the gray tone for an early sowing time between the above-mentioned soils in the green zone is 5 and 6 units respectively, in the IR zone -- 6 and 8 units, in the red zone -- 12 and 18 units.

On photographs in bare fallow, if it is well worked and not overgrown with weeds, the surface soil horizon shows up directly. Against the background of surrounding fields and crops sectors of bare fallow show up most clearly in the IR zone. In the red spectral zone against the general tone of the photoimage they differ slightly from fields occupied by plantings of spring wheat and perennial grasses or virtually do not differ from them. However, within fields of bare fallow the interpretability of different soils is most sharply expressed on photographs taken in the red spectral zone. The difference in the level of the gray tone in this zone (reliability of interpretation) for dark chestnut solonetz-like and meadow-chestnut solonetz-like soils is 12, between dark chestnut solonetz-like and steppe solonetz soils is 10, between meadow-chestnut solonetz-like and solonetz soils is 21.

The soil cover of the dry steppe zone is successfully interpreted through plantings of perennial grasses (crested wheatgrass) and the photoimage of virginland vegetation. For example, through fields of crested wheatgrass dark chestnut sandy loam and light clayey loams in the red zone were reliably discriminated from meadow-chestnut and especially meadow-steppe solonetz soils. Through the virginland vegetation it was possible to determine meadow-chestnut solonchak-like soils, meadow-mixed and complex soil units consisting of meadow-chestnut and meadow-steppe solonetz soils and sectors of meadow solonchaks.

Accordingly, in the dry steppe zone, using summer July photographs taken in different spectral zones, the soil cover is successfully interpreted through the direct images of spring wheat, barley, corn and perennial grasses. This is attributable to the fact that with average harvests in the arid years agricultural crops did not mask the differences in the soil cover, but on the contrary, emphasized them. It is possible that in moist years this effect will be different.

Another important conclusion which can be drawn on the basis of an analysis of the photoimage of multizonal photographs is that in the case of a uniform soils cover (on dark chestnut calcareous clayey soils of extensive plateaus) on the basis of the different tonality of one of the leading crops -- spring wheat -- it is possible to ascertain its crop yield.

Among the spectral zones the best results in the interpretation of the soil cover and agricultural crops were obtained in the red zone. Photographs taken in this zone clearly show dark chestnut calcareous, meadow-chestnut calcareous and dark chestnut calcareous excavated (at mouth of marmot burrows) soils of plateaus; there was reliable interpretation of the complex soil cover with solonetz in the central part of the lands in the territory of an ancient runoff trough; tonal differences between plantings of spring wheat, barley and chick peas were noted better than in the green and IR zones; it was easy to interpret perennial grasses and the soils beneath them. In the IR and green zones these differences were appreciably weaker or there were none. An exception is the photoimage of bare fallow and plantings of corn sown at different times (with different projective covering), which in the IR zone showed up with the greatest contrast.

In autumn, in mid-September 1973, a repeated multizonal aerial survey of the soil cover and agricultural crops was carried out at a medium scale in the green (520 nm), red-orange (610 nm) and IR (840 nm) spectral zones. It coincided with the period of harvesting of grain crops. Therefore, some of the fields at the time of the survey had already been harvested and the photographs showed the stubble of corn and grains on which the soils were being worked with cultivators-levelers. In individual fields it is possible to see spring wheat and barley in the phase of gold ripeness.

An analysis of the characteristics of interpretation of the soil cover and agricultural crops during the autumn survey period indicated the following (Table 36). In the red and IR spectral zones there was reliable discrimination of fields of spring wheat with a yield differing by a factor of 2-2.5 on dark chestnut calcareous soils. In the green zone these differences did not exist.

In sectors of bare fallow with a direct representation of the soil surface on the photographs in general there is a greater brightness of the photoimage of the soil cover (especially solonetz soils) associated with drying out of the upper soil horizon and possibly a greater drawing-out of carbonates to the surface.

In comparison with the summer survey period, in autumn dark chestnut and meadow-chestnut soils are difficult to see under corn in the green and red spectral zones; in the IR zone they cannot be seen. On the other hand, meadow-steppe soils can be seen considerably more sharply (except in the IR zone). This is attributable to the fact that on solonetz soils there is virtually no corn and on the photographs it is possible to see the light surface of the solonetz soils, whereas on dark chestnut and meadow-chestnut soils corn has a well-developed leaf surface which shows up in a dark gray tone. The soil cover can be interpreted through corn stubble only in the IR spectral zone.

During the autumn period meadow-chestnut soils are slightly distinguishable through fields of perennial grasses with dark chestnut solonetz-like soils and solonetz soils, especially in the red zone, can be interpreted very clearly.

In 1974 a multizonal survey in the green (540 nm), red (690 nm) and IR (840 nm) spectral zones was carried out in early July, 1-1.5 months after the sowing of grain crops. The survey was made on a medium scale. On these photographs on the basis of the different photoimage of the grain crops it was easy to see the difference in the moisture supply of the soils, related to their different working. For example, with the sowing of spring wheat at one and the same time (25-26 May, dark chestnut calcareous soils) on photographs in the red and IR spectral zones there was reliable interpretation of the difference between fields in which in 1973 there had been deep loosening of the soil (to 25-27 cm), and in the course of 1971-1973 there had only been a plowing-under of the stubble (to a depth of 8-12 cm) (Table 37). Among fields of barley (dark chestnut calcareous soil, sown 29-30 May) a different tone in the IR zone was characteristic of fields in which there had been bare fallow in 1972, whereas in 1971-1973 there had been plowing-under of the soil. In autumn the yield on these soils was 12.0 and 8.5 centners/hectare respectively (Fig. 34).

On the photographs it was possible to discriminate fields with different times for the sowing of spring wheat (15-16 May, 25-30 May, dark chestnut calcareous soils). Fields sown at different times with the best development of wheat had a darker gray photoimage tone in the red and a lighter gray tone in the IR spectral zone.

Dark chestnut calcareous and meadow-chestnut calcareous soils, dark chestnut solonetzlike, meadow-chestnut solonetzlike, steppe and meadow-steppe solonetz soils, meadow mixed and meadow solonchak soils were reliably interpreted through plantings of grains (spring wheat, barley, millet), chick peas, corn, perennial grasses (crested wheatgrass) and virginland vegetation from aerial photographs in the red spectral zone. In fields where perennial grasses had been mown the interpretability of soils was poor and only areas of meadow-chestnut soils could be seen.

On photographs in the IR spectral zone against a background of agricultural plantings it is very easy to interpret fields with sectors of bare fallow, but internal differentiation of the makeup of the soil cover in them was poor (Fig. 34).

Photographs in the green spectral zone do not give additional new information concerning the soil cover and agricultural crops in comparison with the photographs just considered. With respect to the nature of the photoimage they are close to photographs in the red zone, but for a number of soil-agricultural features have a less sharply expressed contrast.

In 1975 a multizonal survey in the green (540 nm), red (690 nm) and IR (840 nm) spectral zones of the experimental sector was carried out in mid-June. With respect to moistening conditions in the territory of Kazakhstan this year was acutely arid. On the photographs, from the state of development of plantings of winter wheat on dark chestnut calcareous soil in the course of the first month, it can be seen that the photoimage is influenced considerably by the presowing working of the soil. With one and the same sowing times and soil conditions the best development of spring wheat was noted in fields where the presowing working of the soil was carried out with the KPE-3.8 antierosion cultivator to a depth of 12-14 cm and sowing with the SZS-9 drill in comparison with fields where sowing was carried out with the SZS-2.1 drill. These differences were observed most sharply on photographs in the IR spectral zone. The difference in the level of the gray tone of these fields in the green zone was equal to zero, in the red zone 2, and in the IR, which was most sensitive to the development of plants -- 12 (Table 38).

On early summer photographs in the green and especially in the red spectral zones the soil cover was reliably interpreted through plantings of spring wheat, barley, annual and perennial grasses. Over the territory of plateaus it was possible to determine meadow-chestnut soils through plantings of spring wheat against a background of dark chestnut calcareous soils on the basis of a dark tone and affinity to swales; the image of small light dots was indicative of dark chestnut calcareous excavated soils (at the mouth of marmot burrows). In the red zone these soils had a more sharply expressed contrast than on photographs in the green zone. In the IR zone the excavated soils at the mouth of marmot burrows could not be detected, whereas meadow-chestnut soils appeared in a light gray tone similar to the general image background of fields covered with cultivated vegetation.

The complex soil cover of the central part of the territory to be analyzed, occupying the ancient runoff valley, could be seen in detail through plantings of barley and annual grasses (foxtail millet) on photographs in the green and IR zones, but with special contrast on photographs in the red spectral zone.

Fields of freshly plowed bare fallow showed up in all the analyzed zones, but especially sharply in the IR. On fallow, from the direct image of the soil surface, on photographs in the red and green zones it was easier to interpret dark chestnut calcareous, dark chestnut calcareous soils excavated at the mouth of marmot burrows and meadow-chestnut soils. In all spectral zones on the basis of a light gray tone there was reliable discrimination of unworked fields in fallow, covered by solonchaks. Against the image background of these fields on the basis of a dark gray tone there was a clear interpretation of meadow-chestnut soils (especially in the red zone).

In the IR spectral zone these soils had a light gray tone similar to the general image background of fields covered with weedy vegetation.

Through cultivated crops (corn fields) the soil cover was readily interpreted from photographs in the red spectral zone: sandy loam and light clayey loam dark chestnut soils, solonetz-like meadow-chestnut soils and meadow-steppe solonetz soils were discriminated; in the green and IR zones soil differences were poorly visible through corn fields (solonetz soils) or the soils cannot be interpreted (for example, meadow-chestnut soils).

Through plantings of perennial grasses (crested wheat grass) on early summer photographs the complex soil cover (dark chestnut solonetz-like, meadow-chestnut solonetz-like and meadow-steppe solonetz soils) showed up very sharply in the red spectral zone. In the green zone the soils are visible but the image contrast is poor. In the IR the soils are not interpreted; the field has a homogeneous light gray color. Some lightening of the tone can be noted only in solonetz areas.

The soil cover shows up most differentially on photographs in the red spectral zone through virginland vegetation. In particular, this differentiation is associated with a detailed representation of meadow-chestnut soils associated with microswales and longitudinal troughs. In the green and IR spectral zones these soils are virtually not interpreted or can be seen very poorly.

On early summer photographs in the green, red and IR zones meadow and weedy solonchaks are shown in a similar (light or almost white) tone.

Accordingly, for the purposes of objective and reliable interpretation of the soil cover, agricultural crops and virginland vegetation in the territory of the dry steppe in the early summer period it is necessary to use aerial photographs taken in the red (primary) and IR (secondary) zones. IR photographs were particularly valuable material in an analysis of differences in the state of agricultural crops (for example, spring wheat) during initial periods of development of grain crops (tillering and stem extension stages). An analysis of the condition of agricultural crops during this period makes it possible to predict their crop yield.

In conclusion we will cite a composite key table for interpretation of the main soils (Table 39) in the dry steppe zone of Kazakhstan which we prepared on the basis of a soil interpretation of multizonal aerial and space photographs. In the compilation of this table we made an analysis of the photoimage of both small- and medium-scale space photographs.

Interpretation of Multispectral Aerial Photographs of Desert Zone

A new direction in the study and interpretation of the soil cover and agricultural crops is a multispectral photoelectronic survey of the earth's surface.

In photoelectronic methods for the registry of the soil-vegetation cover use is made of multispectral scanning systems (MSSS) -- radiometers, side-view radars and other photoelectronic instruments. Using these methods information on soils and agricultural crops can be registered on magnetic tape or registered in the form of an image on the screen of a cathode ray tube. Photoelectronic methods can be used in the UV (0.01-0.4 μm), in the entire visible zone of the spectrum (0.4-0.76), in the near-IR (0.76-1.1 μm), in the far IR (1.2-25 μm) and in the radiowave spectral region (from 1 mm to several meters).

Using photoelectronic methods it is possible to obtain new additional information on soil-agricultural resources in comparison with aerial photographic methods. This occurs, on the one hand, due to a survey in those parts of the spectrum which are not employed for photography on light-sensitive materials (the sensitivity limit for infrafilm is 1.1 μm); on the other hand, this is due to the use of narrow spectral zones for surveying of the soil-vegetation cover with a considerably greater differentiation on the basis of their spectral brightness.

At recent congresses of the American Photogrammetric Society much attention has been devoted to the problems involved in interpretation and new photoelectronic technical means for obtaining information on the earth's surface. The attention of researchers in this field is being given to obtaining information without a photographic image and solution of the problem of automation of the photointerpretation process (MacDonald, Kristof, 1970).

In the United States, on the basis of an analysis of data from a multispectral scanner obtained during the survey period April-July 1969 it was possible to obtain interpretation criteria (signatures) of soils and agricultural crops -- corn, sorghum, cotton, citrus. It was established that their identifiability is better during the early parts of the growing season (Wiegand, et al., 1971).

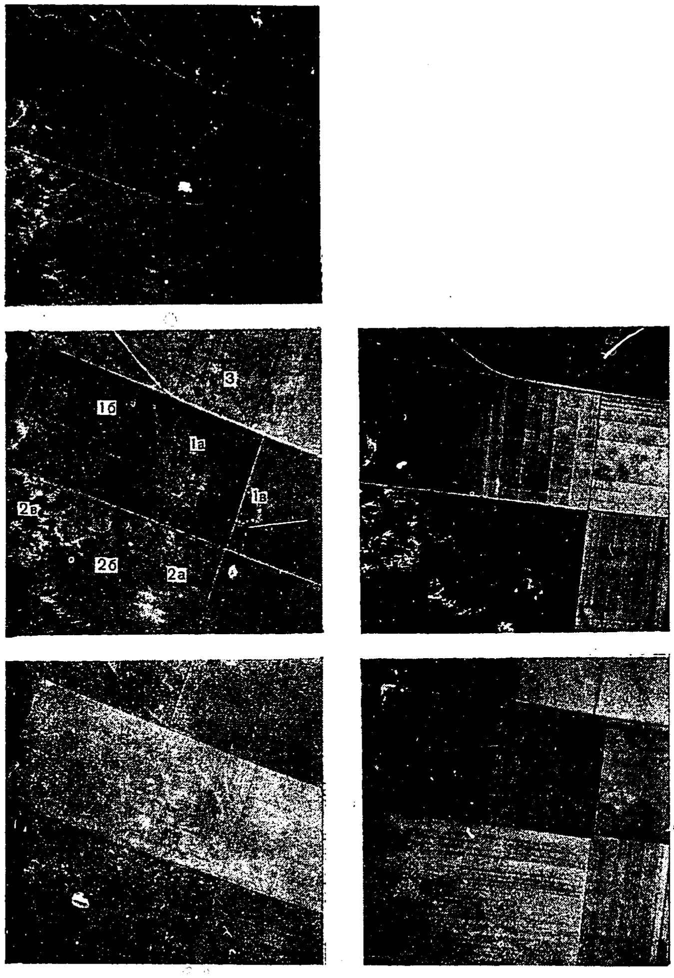

Fig. 33. Change in tone and contrast of photoimage of soils and agricultural crops on multizonal photographs in dependence on spectral zone and season of survey of one of the experimental sectors of the dry steppe territory. Spectral zones: at top -- green; in middle -- red; at bottom -- IR. Survey season: at left -- summer; at right -- early autumn. Mechanical composition of soils -- sandy loam and light clayey loam. 1) corn (early planting) on: a) dark chestnut soils; b) meadow-chestnut soils; c) meadow-steppe solonetz soils (in the early autumn period of the survey the corn had been harvested and stubble is shown); 2) corn (late planting) on: a) dark chestnut soils; b) meadow-chestnut soils; c) perennial grasses (crested wheatgrass) on dark chestnut and meadow-chestnut soils.

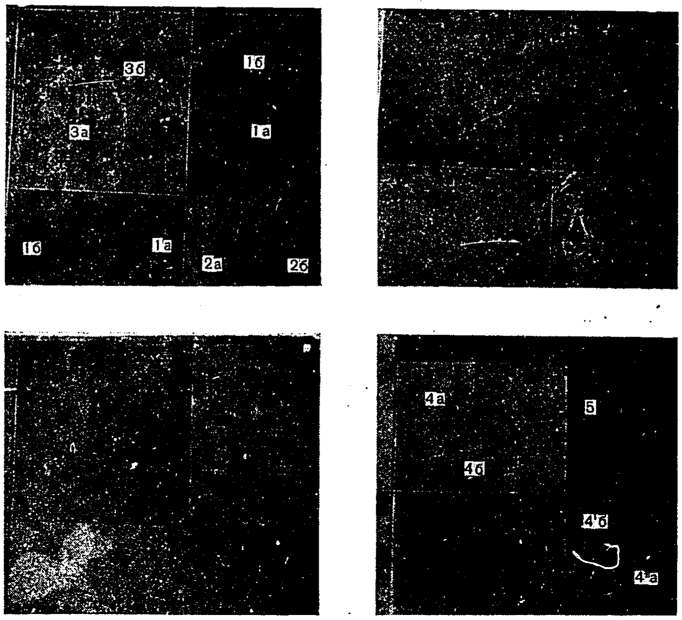

Fig. 34. Photoimage of soil cover and agricultural crops on summer multizonal photographs of territory of two experimental sectors of dry steppe zone of 1974 survey. Spectral zones: at top — red; at bottom — IR. Sectors: at left — flat water divide with swales; at right — gentle slope. Mechanical composition of soils clayey and heavy clayey loam. 1) spring wheat Saratovskaya 29 (late sowing 25-26 May) (in 1973 the soil was loosened to a depth of 25-27 cm); a) dark chestnut calcareous soils; b) meadow-chestnut calcareous soils; 2) spring wheat Saratovskaya 29 (late sowing 25-26 May) (in 1971-1973 the soil was cut to a depth of 8-12 cm) on: a) dark chestnut calcareous; b) meadow-chestnut calcareous; 3) chick peas on: a) dark chestnut calcareous; b) meadow-chestnut calcareous (white dots — image of marmot burrows); 4) barley Yevropeum 353/133 (sowing at end of May) on: a) dark chestnut calcareous; b) meadow-chestnut calcareous soils; 4) harvest 12 centners/hectare (in 1972 was fallow); 4^1 — harvest 8.5 centners/hectare (in 1971-1973 there was deep cutting of the soil); 5) bare fallow.

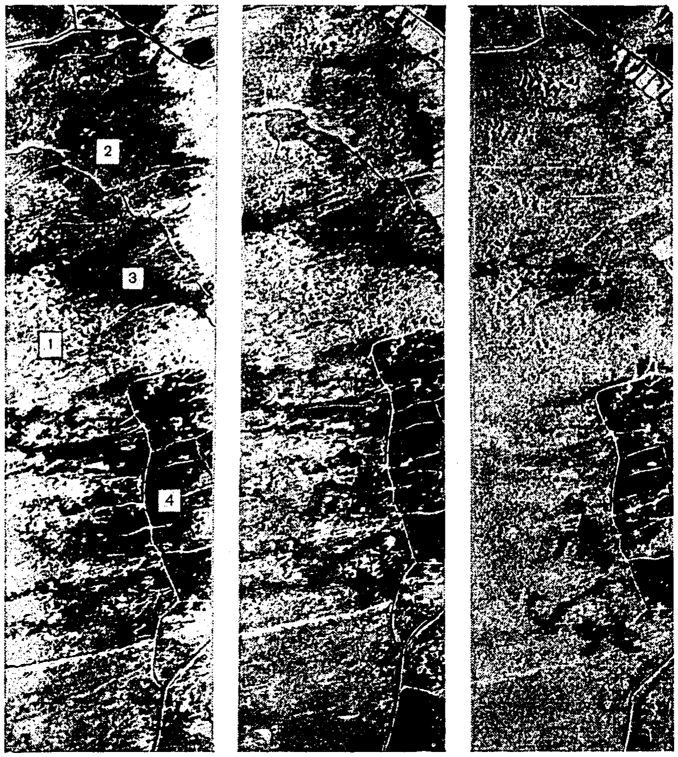

Fig. 35. Multispectral survey of soil cover in desert zone. Photoimage in zone: at left -- 0.4-0.45μm; in middle -- 0.5-0.55μm; at right -- 0.72-0.82μm. 1) barchan deflatable sands; 2) small sand hills, partially consolidated by psammophytic vegetation; 3) depressions between ridges with ground water at shallow depth; 4) utilized areas of gray sands.

A comparison was made of soil maps obtained by usual surface methods and compiled automatically using a multizonal scanner. There was a good similarity for soils differing in color and a noncorrespondence of soils differing with respect to structure, mechanical composition and position in the relief (Baumgardner, et al., 1970; Kristof, Zachary, 1974).

For the successful use of the method of computer analysis of multizonal data on the soil cover the survey must be carried out in a period when the fields are free of vegetation, over a relatively even terrain, with the sun high in the sky (midday) and with availability of data on the soil cover.

Table 30

Boundary Contrast (Interpretability) of Soil Cover, Agricultural Crops and Virginland Vegetation on Multizonal Aerial Photographs of Experimental Sector of Steppe Zone. Survey Time 20 September 1973

Name of bordering features	Difference in levels of gray tone in spectral zones (sensitivity λ max, in nm)		
	(green -- 520)	(red -- 610)	(infra -- 840)
Newly plowed fields (typical, leached and excavated chernozems and meadow-chernozem soils) and			
newly plowed fields (meadow-chernozem soils)	7	4	0
fields after scuffling of stubble (typical, leached and weakly eroded chernozems)	6	5	0
stubble of grain crops (typical chernozems and meadow-chernozem soils)	8	36	22
winter rye (sprouts) (typical chernozems and meadow-chernozem soils)	10	14	0
sugarbeets before harvesting (typical chernozems and meadow-chernozem soils)	1	4	44
corn (typical chernozems and meadow-chernozem soils)	4	16	25
corn (stubble)(typical chernozems and meadow-chernozem soils)	15	30	14
perennial grasses (sweetclover)	17	9	35
virginland steppe	10	25	28
steppe after mowing of hay	10	16	42

Table 31

Boundary Contrast (Interpretability) of Soil Cover, Agricultural Crops and Virginland Vegetation on Multizonal Aerial Photographs of Experimental Sector of Steppe Zone. Survey Time 15 October 1974

Name of bordering features	Difference in levels of gray tone in spectral zones (sensitivity λ max, in nm)		
	green (520)	red (690)	infra (840)
Fall plowing of fields (typical, leached and excavated chernozems and meadow-chernozem soils) and			
winter wheat (tillering phase), sown on:			
bare fallow	2	0	18
occupied fallow (peas)	3	3	5
winter rye	5	11	3
fields with weeds	3	1	9
fodder beets	11	16	26
perennial grasses (clover and sweetclover)	12	13	27
virginland steppe	12	20	21
steppe after mowing of hay	7	12	21

Table 32

Boundary Contrast (Interpretability) of Soil Cover, Agricultural Crops and Virginland Vegetation on Multizonal Aerial Photographs of Experimental Sector of Steppe Zone. Survey Time 5 June 75

Name of bordering features	Difference in levels of gray tone in spectral zones (sensitivity λ max, in nm)		
	green (540)	red (690)	infra (840)
Winter wheat (typical, leached and excavated chernozems), yield 40 centners/hectare and			
winter wheat (typical, leached and excavated chernozems with participation of weakly eroded chernozems), yield 25 centners/hectare (sown on occupied fallow)	10	1	15
winter rye (typical, leached and excavated chernozems)	0	2	6
barley with undersowing of perennial grasses (typical and leached chernozems and meadow-chernozem soils)	3	3	4
peas (same soils)	5	5	1
sugarbeets (typical, leached and excavated chernozem soils and meadow-chernozem soils)	6	15	24
meadow-steppe vegetation (meadow-chernozem soils)	3	3	2

Table 33

Boundary Contrast (Interpretability) of Soil Cover, Agricultural Crops and Virginland Vegetation on Multizonal Aerial Photographs of Experimental Sector of Steppe Zone. Survey Time 9 July 1975

Name of bordering features	Difference in levels of gray tone in spectral zones (sensitivity λ max, nm)		
	green (540)	red (690)	infra (840)
Plowed layer of perennial grasses (typical, leached and excavated chernozems and meadow-chernozem soils) and			
stubble of winter crops (typical chernozems and meadow-chernozem soils)	8	13	10
spring wheat with undersowing of clover (typical chernozems and meadow-chernozem soils)	8	9	12
barley with undersowing of perennial grasses (typical chernozems and meadow-chernozem soils)	10	11	13
barley (typical chernozems and meadow-chernozem soils)	17	28	21
corn (typical chernozems and meadow-chernozem soils)	4	-4	41
sugarbeets (typical chernozems and meadow-chernozem soils)	4	-3	38
meadow-steppe vegetation (meadow-chernozem soils)	5	9	25
meadow-swampy vegetation (alluvial meadow and meadow-swampy soils)	-3	-2	35

AEROSPACE METHODS FOR THE STUDY OF SOILS

BY

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Soil	Humus %	$CaCO_3$ %	Mechanical composition	Reflection coefficient %	Relief	Vegetation, land-use area
Leached meadow-chernozems	7.43	None	Heavy clayey loam	10.2	Central Russian Highland Ravines, troughs shallow troughs, swales	Cultivated land. Meadow vegetation in troughs and ravines
Chernozems, typical, leached and excavated (mouth of marmot burrows)	6.13	None (for excavated 0.93)	Heavy clayey loam	10.4 (for excavated 11.1)	Central Russian Highland Slightly convex watersheds and their slopes	Cultivated land

Table 34. Summary Table-Key for Interpretation of Soils of Steppe Zone of European Part of USSR (in Example of Experimental Sector) from Space and Aerial Photographs. Black-and-White Film. Scale of Aerial Photographs -- Large and Medium, Scale of Space Photographs -- Medium and Small

Soil-forming rocks	Interpretation criteria	
	aerial photographs	space photographs
Deluvial clayey loam	Troughed-dendritic or small-spotty or spotty-troughlike-dendritic patterns of dark gray or almost black tone on plowed sectors or under meadow vegetation in green and red spectral zones or on integral panchromatic photographs. In IR zone under meadow vegetation they have a light, almost white tone; in arable land without vegetation — black. From image pattern these soils are interpreted on early summer photographs through image of cultivated crops but on summer photographs — through spring crops	On small- and medium-scale photographs of spring survey period (IR zone) under meadow vegetation these soils clearly determined from almost white tone of image of steppe troughs and gullies. In plowed sectors meadow-chestnut soils not seen in swales and elongated troughs. On summer photos of visible and IR zone interpreted less clearly from troughlike-dendritic pattern
Loessial calcareous clayey loam	On panchromatic air photos and photos in green and red zones soils have monotonic structureless image of almost black tone for fresh plowing or dark gray for dry surface of soils; in IR zone, black tone. Sectors of predominant occurrence of leached chernozems are interpreted only in short early spring period (after snow disappears) from large-spotty pattern of almost black tone (due to increased soil moisture content in comparison with surrounding sectors). Excavated thick chernozems virtually not visible on cultivated land	Soils show up in uniform dark gray or almost black tone in dependence on survey time. Differences in leaching and excavation of chernozems not visible. On summer photos difficult to interpret chernozems through multifield image of fields. Best results obtained from spring-autumn photographs

Soil	Humus	$CaCO_3$	Mechanical composition	Reflection coefficient %	Relief	Vegetation, land-use area
	%					
Chernozems typical:					Central Russian Highland. Watershed slopes near ravines, sides, amphitheater and slopes of ravines	Cultivated land. Slopes with perennial grasses. Edges and slopes of ravines under meadow-steppe vegetation
slightly eroded	5.48	5.79	Heavy clayey loam	12.6		
moderately eroded	2.95	12.39	Same	22.0		

Table 34 (continued)

Soil-forming rock	Interpretation criteria	
	aerial photographs	space photographs
Loessial calcareous clayey loam	On photographs of visible (especially red) spectral zones weakly eroded chernozems show up as low-contrast shallow troughs or fanlike-shallow trough pattern of gray and light gray tone and medium-eroded chernozems show up as clear striated-rill or spotty-shallow trough-rill pattern; in IR zone this pattern is leveled. On summer photos rills overgrown with weedy vegetation show up on cultivated land through crop image. On large- and medium-scale photos on the basis of form and size there is reliable determination of elements of linear erosion -- rills, channels, ravines	On small- and medium-scale photographs easy to determine gully-ravine network on basis of dendritic-spotty-multifield pattern. Natural regions and watersheds with different dissection of territory by gully-ravine network are discriminated. Good results are obtained with use of photos in red and IR spectral zones

Table 35

Boundary Contrast (Interpretability) of Soil Cover, Agricultural Crops and Virginland Vegetation on Multizonal Aerial Photographs of Experimental Sector of Dry Steppe Zone. Survey Time 19 July 1973

Name of bordering features	Difference in levels of gray tone in spectral zones (sensitivity λ_{max}, nm)		
	green (540)	red (610)	infra (840)
Spring wheat Saratovskaya 29 on dark chestnut calcareous clayey soils and on			
meadow-chestnut calcareous soils	4	16	3
dark chestnut excavated calcareous soils (at mouth of marmot burrows)	12	13	0
meadow-steppe solonetz soils	6	5	10
meadow-chestnut solonetz-like soils	3	17	11
meadow solonetz-like soils	6	22	3
dark chestnut solonetz-like soils	5	10	15
meadow-chestnut weakly solonetz-like	1	16	11
steppe solonetz soils	11	4	8
Fallow on meadow-chestnut solonetz-like soils and on			
dark chestnut solonetz-like	5	11	6
steppe solonetz soils, light clayey loam and sand-permeated	13	21	8
Corn (early sowing 20 May) on dark chestnut sandy loam and light clayey loam sand-permeated soils and on			
meadow-chestnut solonetz-like light clayey loam soils	4	10	6
meadow-steppe solonetz soils	8	10	2
Perennial grasses (sweetclover) on dark chestnut solonetz-like soils and on			
meadow-chestnut solonetz-like	3	8	5
fine meadow-steppe solonetz soils	20	6	8
Virginland vegetation -- mixed grass-feathergrass -sheep's fescue on dark chestnut sandy loam and light clayey loam sand-permeated soils and			
sheep's fescue-wormwood-mixed grasses with thrift on meadow-chestnut solonchak-like soils	1	5	3
quack grass-mixed grasses with thrift on meadow-compact heavy clayey loam soils	5	2	22
wormwood-sheep's fescue with thrift on meadow-steppe solonetz soils and meadow-chestnut solonetz-like soils	4	8	3
wormwood-thrift on meadow solonchaks	7	13	14

Table 36

Boundary Contrast (Interpretability) of Soil Cover, Agricultural Crops and Virginland Vegetation on Multizonal Aerial Photographs of Experimental Sector of Dry Steppe Zone. Survey Time 12 September 1973

Name of bordering features	Difference in levels of gray tone in spectral zones (sensitivity λ max, nm)		
	red(520)	red(510)	infra (840)
Spring wheat Saratovskaya 29 (on dark chestnut calcareous clayey soils) and with yield twice as great	0	16	24
Spring wheat Saratovskaya 29 on dark chestnut solonetz-like soils and on			
meadow-chestnut solonetz-like	4	6	1
steppe solonetz soils	6	13	12
meadow-steppe solonetz soils	2	14	20
meadow solonetz-like	10	13	11
Fallow on meadow-chestnut solonetz-like soils and on			
dark chestnut solonetz-like	7	9	11
steppe light clayey loam solonetz soils	17	16	32
Corn on dark chestnut sandy loam and light clayey loam sand-permeated soils and on			
meadow-chestnut solonetz-like and light clayey loam soils	3	7	0
meadow-steppe solonetz soils	12	18	4
Perennial grass (crested wheatgrass) on dark chestnut solonetz-like soils and on	1		
meadow-chestnut solonetz-like	1	2	4
meadow-steppe fine solonetz soils	10	20	11
Virginland mixed grass-feather grass-sheep's fescue vegetation on dark chestnut sandy loam and light clayey loam sand-permeated soils and			
sheep's fescue-wormwood-mixed grass with licorice on meadow-chestnut solonchak-like soils	2	4	2
feathergrass-mixed grass with thrift on meadow-compact heavy clayey loam soils	6	9	16
wormwood-sheep's fescue with thrift on meadow-steppe solonetz soils and meadow-chestnut solonetz-like soils	5	12	10
wormwood-Russian thistle on meadow solonchaks	6	20	12

Table 37. Boundary Contrast (Interpretability) of Soil Cover and Agricultural Crops on Multizonal Aerial Photographs of Experimental Sector of the Dry Steppe Zone. Survey Time 6 July 1974

Name of bordering features	Difference in levels of gray tone in spectral zones (sensitivity λ max, in nm)		
	green (520)	red (690)	infra (840)
On dark chestnut calcareous clayey soils spring wheat (early sowing -- 15-16 May, in 1972 fallow) and			
spring wheat (late sowing -- 25-26 May, in 1973 deep loosening)	13	2	7
spring wheat (late sowing -- 25-26 May, in 1971-1973 deeply cut)	13	7	17
barley (yield 12.0 centners/hectare, in 1972 fallow, sowing 29-30 May)	17	9	7
barley (yield 8.5 centners/hectare, in 1971-1973, deep cutting of soil, sowing 29-30 May)	17	7	24
chick peas	8	11	8
fallow	13	2	28
Spring wheat Saratovskaya 29 on dark chestnut calcareous clayey soils (in 1974 deep loosening of soil, late sowing 25-26 May) and			
deep loosening in 1973, late sowing 25-26 May	5	1	2
in 1971-1973 deep cutting, late sowing 25-26 May	0	4	9
Barley Yevropeum 353/133 on dark chestnut solonetz-like soils and on			
meadow-chestnut solonetz-like	1	6	0
steppe solonetz	8	17	8
meadow-steppe solonetz	5	7	0
meadow solonetz-like	1	9	18
Millet on dark chestnut solonetz-like soils and on			
meadow-chestnut solonetz-like soils	5	3	2
steppe solonetz	12	21	0
meadow-steppe solonetz	7	5	0
meadow solonetz-like	5	4	1
Fallow on dark chestnut calcareous clayey soils and on			
meadow-chestnut calcareous	3	3	0
dark chestnut calcareous excavated soils (mouth of marmot burrows)	5	7	0

Table 38

Boundary Contrast (Interpretability) of Soil Cover and Agricultural Crops on Multizonal Aerial Photographs of Experimental Sector of Dry Steppe Zone. Survey Time 12 June 1975

Name of bordering features	Difference in levels of gray tone in spectral zones (sensitivity λ max, in nm)		
	green (540)	red (690)	IR (840)
On dark chestnut calcareous clayey soils -- spring wheat (sown 16-17 May with SZS-9 drill with presowing working of soil with KPE-3.8 at depth of 12-14 cm) and			
spring wheat (sown 16-17 May with SZS-2.1 drill-cultivator)	0	2	12
spring wheat (sown 26 May in 1974 fallow)	6	2	3
freshly plowed fallow	6	1	16
fallow, covered with weeds	10	6	0
Yevropeum barley 353/133 on dark chestnut solonetz-like soils and on			
meadow-chestnut solonetz-like soils	5	10	7
steppe solonetz soils	8	11	7
meadow-steppe solonetz soils	6	12	6
meadow solonetz-like soils	1	2	1
Freshly plowed fallow on dark chestnut calcareous clayey soils and on			
meadow-chestnut calcareous soils	4	5	0
Corn on dark chestnut sandy loam and light clayey loam (with sand) soils and on			
meadow-chestnut solonetz-like soils	0	8	0
meadow-steppe solonetz soils	4	8	3

Soils	Humus %	CaCO$_3$	Mechanical composition	Reflection coefficient %	Relief	Vegetation, land-use area
Dark chestnut calcareous	3.40	3.31	Clay	20.0	Plateaus: a) flat watersheds;	Cultivated land
Dark chestnut calcareous excavated (marmot holes)	2.68	7.38	Heavy clayey loam	24.4	b) microhillocks on watersheds and at edges of troughs;	Cultivated land
Meadow-chestnut calcareous	3.65	3.75	Clay	19.1	c) swales and troughs	Cultivated land
Dark chestnut of light mechanical composition	1.41	None	Sand, more frequently sandy loam	16.2	Undulating sandy plain: a) slightly convex watersheds	Cultivated land more rarely; more frequently virginland sheep's fescue-feathergrass-mixed grass with participation of wormwood

Soil-forming rock	Interpretation criteria	
	aerial photographs	space photographs
Covering calcareous clays and heavy clayey loams underlain by Paleogene deposits	Dark chestnut and meadow-chestnut soils are interpreted from summer survey period photographs in the red spectral zone through the image of grain crops from the three soil cover components. The meadow-chestnut soils have a spotty or slightly dendritic pattern of a dark gray tone. They are differentiated poorly in the green and IR zones. In the green and red zones the excavated soils at the mouth of marmot holes are not masked by plantings of grain crops; they have a dotted pattern of almost white tone and are not visible in the IR. During autumn in plowed sectors the interpretation of soils was more reliable from photographs in the red spectral zone	Soil cover of these three components has a multifield spotty or spotty-slightly dendritic image pattern of dark gray tone on photographs of spring, summer and autumn periods of survey; it is clearly expressed on photographs of small and medium scales and is associated with image of meadow-chestnut soils against a background of dark chestnut calcareous; dark chestnut excavated (mouths of marmot holes) not visible
Sandy and sandy loam Quaternary deposits	Moiré pattern of gray and light gray tone characteristic for photoimage of these two components of the soil cover of virginland and especially cultivated sectors (areas of grasses, grains or crop-free soil surface); it is clearly visible on photographs in the red spectral zone and is leveled or absent in the IR. Pattern governed by combination of chestnut sandy loam soils formed on micro- and mesorises: crests, ridges, spurs and meadow-chestnut soils (dark gray tone) associated with swales and depressions between ridges	On small- and especially medium-scale photographs easy to see a moiré pattern of gray and light gray tone characteristic for these soils. Using photo it is possible to interpret orientation, extent and width of sand ridges and depressions between ridges. Deflatable sands have a spotty pattern of a light tone. Inter-ridge depressions and troughs with meadow-chestnut soils show up in dark gray tone

Soils	Humus	CaCO$_3$	Mechanical composition	Reflection coefficient %	Relief	Vegetation, land-use area
	%					
Dark chestnut solonetz-like	2.67	0.20	Clayey loam	14.9	Ancient runoff trough (slightly undulating plain): a) watershed;	Cultivated land or virginland mixed-grass-sheep's fescue-wormwood
Meadow-chestnut solonetz-like	3.42	None	Clayey loam	12.5	b) troughs; swales;	Cultivated land or meadow-steppe virginland
Steppe solonetz	1.75	None	Clay, clayey loam	24.3	c) microrises;	Cultivated land, virginland
Meadow-steppe solonetz	2.00	None	Clay, clayey loam	21.3	d) microrises on low parts	Cultivated land, virginland
Meadow solonchaks	0.41	3.40	Clay	38.1	Marginal parts of lacustrine depressions	Wormwood-Russian thistle
Salina solonchaks	At surface light crust of salts		Clay	40.8	Lacustrine basins	Vegetation absent

Table 39. Summary Table-Key for Interpretation of Soils of Dry Steppe Zone of Kazakhstan from Aerial and Space Photographs. Black-and-White Film. Scale of Aerial Photographs Large and Medium; Scale of Space Photographs Medium and Small

Soil-forming rock	Interpretation criteria	
	aerial photographs	space photographs
Saline clayey loams and variecolored clays Saline deluvial clayey loams Saline Tertiary rocks: clays and clayey loams	Photoimage of complex soil cover has a complex conchoidal, sharply defined pattern, consisting of soil units of gray (dark chestnut solonetz-like), dark gray, almost black tone of troughed-dendritic texture (meadow-chestnut solonetz-like) and soil units of light gray (meadow-steppe solonetz) and light tone (steppe solonetz). This complex soil cover in the red spectral zone is interpreted better through the open soil surface, plantings of grains and grasses, and also on virginland; in the IR soil differences are not visible or poorly visible through crops. On photos in the visible zone virgin land has darker tones	On medium-scale photographs reliable interpretation of complex dendritic openwork-serrated-conchoidal pattern of light gray, gray and dark gray image tone of soils in this territory of an ancient runoff valley. Steppe solonetz soils are discriminated by having a lighter tone than meadow-steppe solonetz soils. The described pattern is very clearly visible from the open surface
Saline lacustrine clays and clayey loams Saline lacustrine deposits	On summer photos in the visible and IR spectral zones the dessicated surface meadow and salina solonchaks show up in similar light or almost white tone (due to light salt crust on surface). Due to association of solonchaks with marginal part of bitter salt lakes these are reliably interpreted from spotty or crescent-like contours. In moist state -- dark gray tone (usually in early spring or late autumn)	Spotty or crescent-like form of soil units of solonchaks of almost white tone. In moist state solonchaks show up in a dark gray tone. In small areas of solonchaks (less than 0.5 cm^2) on small- and medium-scale photographs they form areas having a pock-marked photoimage pattern

In 1973 an experiment was carried out for testing instrumentation for the remote sensing of the earth's surface from an aircraft. The complex of on-board instrumentation included a multispectral scanning system (MSSS) and a system for digital videorecording (Khodarev, et al., 1974; Ziman, et al., 1975). The scanning apparatus made it possible to obtain images in four spectral zones: 0.4-0.45, 0.5-0.55, 0.6-0.68 and 0.72-0.82 μm. The survey was made on 14 June at 1200 hours from an altitude of 5,200 m at a small scale.

In a diagnostic interpretation of multispectral photographs we used data from field soil investigations carried out in the summer of 1973 and materials from large- and medium-scale soil maps of this experimental sector.

In soil-geographic respects the investigated region took in a part of the Fergana valley. The soil cover (zone of gray soils) was represented by gray-brown gypsum-bearing soils, gray soils, irrigated gray soils, meadow-swampy soils on alluvial-proluvial deposits with the participation of solonchaks and gray sands.

An analysis of the image of the soil cover and agricultural crops from multizonal materials revealed the following. In two of the four spectral zones used when working with the MSSS (0.5-0.55 and 0.6-0.68 μm) there was a similar photoimage of the earth's surface, including the soil cover. Among the remaining zones the greatest information content with respect to the interpretation of agricultural crops and soils was from photographs taken in the zone 0.4-0.5 μm. On the basis of the nature of the photoimage it was possible to determine gray-brown and gray soils, irrigated gray soils and meadow-gray soils and separate meadow-swampy old irrigated slightly saline soils of heavy and medium clayey loam mechanical composition from newly irrigated slightly upgraded somewhat saline soils of clayey loam and light clayey loam mechanical composition with the participation of sandy soils. However, they were interpreted with difficulty.

It was considerably easier to discriminate newly irrigated meadow-swampy moderately saline soils with spots of weak and strong salinization and especially newly exploited highly saline soils with the participation of solonchaks and gray sands. The latter had a clearly expressed mottled, unordered photoimage pattern of a light gray and dark gray tone. The appearance of this pattern (but to a lesser degree) could be observed in areas of newly irrigated moderately saline soils. The image of the soil cover on photographs obtained in the zones 0.5-0.55 and 0.72-0.82 μm was characterized by a greater uniformity, except for newly utilized highly saline soils.

The characteristics of the soil cover in the irrigated zone, clearly reflected in the zone 0.4-0.45 μm, are calcareousness and differences in surface soil moisture content. The soils of the analyzed sector in the upper horizon contained a small quantity of humus (0.93-1.37%) and a high percentage of carbonates (5-11% CO_2 or above). They were characterized by a high reflectivity in dry and even in moist states and on the photographs showed up in a light tone. Moistening was manifested in a grayer tone.

Table 40

Boundary Contrast (Interpretability) of Soil Cover of the Desert Zone on Multispectral Photographs. Survey Time 14 June 1973

Name of bordering units	Difference in levels of gray tone in spectral zones (sensitivity λ in μm)		
	0.4-0.45	0.5-0.55	0.72-0.82
Utilized areas of gray sands and barchan deflatable sands	27	27	21
small sand hills, partially consolidated by psammophytic vegetation	4	16	18
depressions between ridges with ground water at shallow depth	0	0	5

In the zone 0.5-0.55μm the moist soil surface was represented by a dark-gray tone, whereas a dry surface had a bright-light tone. Differences in surface moistening showed up in considerably greater detail on photographs obtained in the zone 0.4-0.45μm. Visually it was possible to make reliable discrimination of 5-6 gradations of soil moisture content from the change in the gray tone.

With the photographs there was reliable determination of the photoimage characteristics of sandy areas in the desert zone. For example, barchan deflatable sands were reliably interpreted from a light gray and almost white tone and a crescent shape. A light gray tone with individual small sectors of gray tones (typical for depressions between ridges) was characteristic for small hills of sand partially consolidated by psammophytic vegetation. Depressions between ridges with the ground water close to the surface and utilized areas of gray sands were clearly determined from a dark gray and almost black photoimage tone (Fig. 35). Table 40 gives the interpretability of sandy areas in different spectral zones. It shows that the greatest differentiation in their photoimage is observed in the spectral zone 0.4-0.45μm. However, the most complete and objective characterization of the considered features is possible with the joint use of photographs in the three considered zones.

The joint use of photographs obtained in different spectral zones made it possible, on the basis of the change in tone, to interpret correctly the agricultural crops and also their state. In fields with cotton plantings there was reliable discrimination of five different degrees of moistening of the soil surface. It is possible to discern fields of mown and unmown alfalfa and Sudan grass and sectors planted in grapes can be interpreted amidst the gardens.

On photographs taken in the zone 0.5-0.55 and especially 0.72-0.82 μm these interpretation characteristics are difficult to make out or are not determined at all.

Thus, the use of data from a multispectral scanning system made it possible with a high degree of detail to study the soil cover of an irrigated zone of gray soils and the state of agricultural crops in a cotton-alfalfa crop rotation.

Chapter 7

MULTIZONAL SPACE METHODS FOR STUDYING THE SOIL COVER

During recent years a multizonal space survey has come into increasingly broader use in the complex of aerospace methods for study of the earth's natural resources, including the soil-vegetation cover. This is attributable to the fact that using the photographs this method makes it possible to determine both the geometrical and spectral characteristics of features. It makes it possible to make a quantitative evaluation of soil and agricultural features on the basis of their photoimage on photographs.

As a result of the carrying out of a multizonal space survey of the soil-vegetation cover (depending on the number of selected spectral survey zones) it is possible to obtain a series of black-and-white photographs which carry information on the characteristics of spectral reflection of soils and agricultural crops. During the flight of the "Apollo-9" the survey was made using four cameras. In the first Soviet space multizonal experiment on the "Soyuz-12" use was made of nine zones; during flights of the American ERTS satellite -- four zones; in the experiment with the "Skylab" orbital station -- 13 zones; with the "Salyut-4" orbital station -- three zones and a color film; in the joint "Raduga" experiment of the USSR and the GDR in a survey from the "Soyuz-22" -- six spectral zones; in flights of the "Meteor" experimental satellites -- four zones.

In the processing of a number of zonal (spectrally differentiated) photographs the spectral characteristics of the soils and agricultural crops, manifested in a different tonality of the photoimage, are an important additional interpretation criterion in comparison with an ordinary (integral) survey in one zone.

In order to increase the effectiveness of use of materials from a multizonal survey it is of great importance to choose those spectral survey zones in which the greatest differences are observed in the brightness characteristics of soils and plants. Another important problem is the determination of soils and their properties, whose interpretation will give the maximum effect in a definite spectral zone.

Interpretation of Soils from Multizonal Space Photographs Taken from the "Soyuz-12" and "Salyut-4"

A multizonal space survey from the "Soyuz-12" was made in September 1973 by the USSR flier-cosmonauts V. G. Lazarev and O. G. Makarov. About 100 photographs of the earth's surface in different spectral zones were taken.

The multizonal survey was made using an apparatus constituting a nine-objective three-channel camera. Using selective light filters the survey was made on three films of different spectral sensitivity -- 0.47, 0.54, 0.58, 0.64, 0.66 and 0.68 μ m. Photographs synthesized in natural colors (Fig. 36, see insert) have high interpretation qualities.

Now we will give an analysis of the characteristics of soil interpretation on the basis of space photographs taken in these six spectral zones of the territory of the Buzachi Peninsula and Tyub-Karagan -- the northern part of the Mangyshlak Plateau. In the diagnostic interpretation of soils we used medium- and small-scale soil maps of Kazakhstan.

On the photographs it is possible to interpret the Mangyshlak Plateau with gray-brown solonetz-like soils having a gray and light gray image tone and gray-brown solonchak-like soils primarily of a dark gray and gray tone. Except for the blue zone, these soils are readily differentiated from one another in all the remaining spectral zones. Against the image background of all these soils it is possible to see bright spots of solonchaks and oval shapes of an almost black tone -- lakes. In the marginal part of the level limestone Mangyshlak and Tyub-Karagan Plateaus on the basis of a dendritic pattern of a light tone it is easy to distinguish gullies. On the photographs from an uneven white band there is reliable interpretation of a limestone bluff -- the Severnyy and Yuzhnyy Aktau cuestas -- and linear erosional dissection of the gentle slopes of cuestas with eroded gray-brown solonchak-like soils and bedrock outcrops.

On photographs in all zones (except for 470 nm) it is easy to see a feature with a dark tone, the Karatau Range, extending from northwest to southeast, consisting of dark-colored metamorphic sandy-clayey rocks on which chestnut soils have formed under a grassy-semidesert vegetation.

On the shores of the southern part of Mangyshlak Gulf sands were interpreted on the basis of the almost white tone of the photoimage in all zones (except for 540 nm and especially 470 nm, where the feature has a light gray, almost gray image tone).

The Buzachi Peninsula is a slightly hilly plain with depressions having internal runoff and eolian relief forms. On the basis of the photoimage characteristics this territory can be clearly divided into two parts: slightly and moderately saline with gray-brown solonchaks (tone of photoimage dark gray) and highly saline with a high percentage of solonchaks (tone of photoimage light gray, openwork pattern).

In the green (0.54μm) and especially in the blue (0.47μ m) zones there is reliable differentiation of sands, having a light gray, almost gray tone, and solonchaks, which are characterized by an almost white image tone.

In the remaining spectral zones they are characterized by a similar tone (Kravtsova, Antonova, 1976).

Our investigations of the interpretability of the soil cover from multizonal photographs from the "Soyuz-12" indicated that for a reliable office determination of soils it is necessary to use photographs of not less than three zones of the visible part of the spectrum (blue, green, red), since they visually (repeated three times) confirm the discrimination of one and the same soil units; at the same time, photographs of individual zones make it possible to discriminate soils with a similar photoimage.

A multizonal space survey from the long-lived orbital station "Salyut-4" was made in June 1975 by the USSR flier-cosmonauts P. I. Klimchuk and V. I. Sevast'yanov. The photosurvey was made from an altitude of 340 km. The scale of the original photographs was 1:4,200,000. One of the cameras was used in color photography; the other three were used in making a black-and-white survey in three spectral zones: 0.5-0.6, 0.6-0.7, 0.7-0.8 μm. Later the photographs were enlarged to scales of 1:2,000,000 and 1:1,000,000 and space photographs in conventional colors were obtained by optical synthesis from three initial black-and-white images.

We made an interpretation of the soil cover from these samples of multizonal photoinformation at a scale of 1:1,000,000 with the use of small-scale soil maps. Multizonal space photographs show the mountainous region of the Central Tien Shan in the region of Lake Issyk-Kul'. On photographs of all zones there is a contrasting (white tone) representation of the high-mountain regions of the Kirgiz Range, Terskey-Alatau, Kungey-Alatau, Zailiyskiy Alatau, covered with snow fields and glaciers. Adjacent to these is a zone of mountainous meadow alpine and meadow-steppe subalpine soils which was reliably interpreted from a color photograph, color synthesized and black-and-white photographs in the zones 0.5-0.6 and especially 0.6-0.7μm. On a black-and-white photograph in the zone 0.7-0.84 μm the image of the soil cover had a low contrast.

The next zone of mountain chernozems and mountain chestnut soils was better interpreted from photographs (especially color synthesized photographs) on the northwestern slopes of the Zailiyskiy Alatau. Color and black-and-white photographs were used in determining the soil cover of the territory of the Internal Tien Shan, represented by mountainous chestnut and mountain-lowland gray-brown soils. On the photographs it is easy to interpret the Issyk-Kul' basin, bordered by ranges, with light brown and gray-brown desert rubbly soils. In the territory of the Internal Tien Shan, on the basis of the nature of the relief and tonal differences, it was possible to determine intermontane depressions: Kachkorskaya, Dzhumgal'skaya, Narynskaya. These basins, made up of unconsolidated Tertiary and Quaternary sediments with mountain-lowland gray-brown soils, are the principal regions of irrigated crop cultivation in the analyzed territory.

On black-and-white photographs gray-brown desert soils are represented by a light gray tone, on color photographs -- by a rosy-yellow tone and irrigated sectors by a dark gray or greenish brown color. A high-mountain depression with Lake Sonkel', with chestnut, meadow and moist meadow soils, was represented on the photographs by a darker tone.

The territory of the irrigated zone of the Chuyskaya valley with gray-brown irrigated soils, typical and irrigated gray soils, was interpreted on the photographs from a multifield square-rectangular pattern of the photoimage of a dark gray tone or a greenish-brown color (on a color photograph). The darkest unit of old irrigated meadow soils was clearly expressed against the image background of these soils in the central part of the valley.

A comparative analysis of different photographs obtained by optical synthesis indicated that the best differentiation of the soil cover in the mountainous part of the Internal Tien Shan and intermont basins was obtained from a photograph on which the zone 0.5-0.6 μm had a blue color, the zone 0.6-0.7 μm had a green color and the zone 0.7-0.84 μm had a red color.

Interpretation of Soils and Vegetation from Multispectral Space Photographs from the "Landsat" ERTS

In the investigation of the earth's natural resources from space a special place is occupied by the United States specialized resources satellite ERTS. Its use for the first time made it possible to ensure, with a good resolution (80-100 m), a systematic multizonal survey of the entire earth and accomplish routine transmission of images to ground stations. In the very first years of operation of this satellite in the United States there were 550 requests from different countries for the collection and processing of materials from the ERTS satellite. With each passing year these photographs are being used more and more extensively for study of the earth's natural resources.

In investigations of the agricultural use of lands in the state of Texas in the United States on the basis of January and May photographs taken from the "Landsat-1" a study was made of the type of agricultural crops, moistening conditions, soils, areas of fields, degree of their projective coverage and height of the crops. In the machine interpretation of the extent of the fields, beginning with 6 hectares, and the differences in soils, the best result was obtained when using data in the zones 0.6-0.7 and 0.8-1.1 μm. Similar results were obtained using materials from January and May flights. In the territory of irrigated regions in the United States irrigated agricultural crops were interpreted using photographs from the "Landsat-1" for the July survey period amidst unirrigated crops and clean fallow. Corn, sugarbeets and alfalfa were clearly determined. "Landsat" images make it possible to compile maps at a scale of 1:250,000 or less, to determine irrigated and unirrigated lands, pastures, swamps, individual types of agricultural crops, main types of soils, distribution of eroded lands, etc. The seasonal development of sown crops is traced from them.

The information obtained from the multizonal photographs from the ERTS differs greatly in dependence on the spectral zone and the season of the survey. Photographs of 9 October and 20 December 1972 were analyzed for the territories of the Vosges and Alsace valley. The green zone (0.5-0.6 μm) is poor for the study of natural resources. The zone 0.6-0.7μ m was effective for the study of vegetation. The most precise and diversified information on the nature of relief and the vegetation cover was obtained in the zone 0.7-0.8μ m. Meadows in moistened valleys and cultivated land on loessial rocks were clearly discriminated. On photographs in the zone 0.8-1.1μm on the basis of the change in the gray zone it was possible to discriminate sandstones from limestones and alluvial deposits.

Photographs of the territory of British Columbia (Canada) from the ERTS indicated that in the zone 0.8-1.1μm moistened soil surfaces differ sharply from sectors of dry soils covered with vegetation.

In the zones 0.5-0.6 and 0.6-0.7μ m forests were clearly differentiated with respect to age composition but moist meadows could not be distinguished from pastures.

Meadows and pastures were reliably determined in the zones 0.7-0.8 and 0.8-1.1μ m.

In a study of the territory of unexploited lands on photographs from the ERTS it was established by American specialists that the zone 0.5-0.6μm was most effective for the interpretation of roads and river valleys and the zone 0.6-0.7 μ m for the study of agricultural crops, pastures and forests. Cultivated lands and water showed up best in the zone 0.8-1.1μm.

Thus, images from each channel give different information on the terrain and together a number of channels supplement one another. As a result, the volume of information becomes so great that the need arises for using electronic computers for its processing.

A number of photographs from the ERTS satellite were taken over the territory of the USSR. Using these photographs we investigated the possibility of interpretation of the soil cover of the desert and steppe zones and ascertained the most promising spectral ranges for studying soils. Now we will examine space photographs of the Fergana valley obtained using a multispectral scanning apparatus from the ERTS-1 satellite. This apparatus operated simultaneously in four spectral zones: 0.5-0.6, 0.6-0.7, 0.7-0.8, 0.8-1.1μm; the survey was made on 24 June 1973 from an altitude of about 900 km (Fig. 37).

Table 41

Data from Visual-Instrumental Interpretation of Soil Cover in Fergana Valley from Multizonal Space Photographs Taken from ERTS Satellite. Survey Time 24 June 1973

Soils	Difference in levels of gray tone in spectral zones λ max (in μm)		
	0.5-0.6	0.6-0.7	0.8-1.1
Typical gray soils, light gray soils and gray-brown soils of adyry and			
irrigated gray soils and meadow-gray soils	10	10	6
irrigated meadow-gray soils and meadow-boggy soils	18	12	6
gray sands and meadow solonchaks	3	0	2
mountain gray soils	3	2	2
mountain cinnamon soils	22	24	5

Table 42

Boundary Contrast (Interpretability) of Soil Cover (in Comparison With Solonetz-Solonchak Soils) in Southeastern Kazakhstan from Multizonal Space Photographs (Positive Film). "Raduga" Experiment for Survey Time 17 September 1976

Soils	Difference in Levels of Gray Tone in Spectral Zones (λ in nm)					
	blue (480)	green (540)	orange (600)	red (600)	infrared	
					720	820
Chernozems of intermontane basins	15	11	10	12	6	9
Chestnut clayey loam	12	7	6	7	4	7
Light chestnut sandy loam	6	5	4	3	3	5
Brown desert-steppe	11	7	8	10	3	6
Brown meadow-steppe	15	9	10	13	5	9
Gray-brown desert sandy loam	2	2	1	0	1	2
Gray-brown desert with outcrops of quartzy sandstones	16	11	12	14	6	12
Gray-brown desert solonetz-like clayey loam	13	7	8	10	4	8
Gray soils, low degree of calcareousness	8	6	6	6	3	7

Table 42 (continued)

Soils	Difference in Levels of Gray Tone in Spectral Zones (λ in nm)					
	blue (480)	green (540)	orange (600)	red (600)	infrared 720	820
Irrigated meadow-gray soils	3	4	3	1	1	3
Solonchaks	0	1	0	2	1	2
Salina solonchaks	3	1	2	4	1	3
Meadow-swampy	13	11	13	16	6	7
Alluvial-meadow	16	7	14	16	4	7
Sands	6	6	6	6	4	8

Table 43

Boundary Contrast (Interpretability of Soil Cover of Southeastern Part of Kazakhstan from Multizonal Space Photographs (Positive Film)). "Raduga" Experiment. Survey Time 17 September 1976

Soils	Difference in Levels of Gray Tone in Spectral Zones (λ in nm)					
	blue (480)	green (540)	orange (600)	red (600)	infrared 720	820
Light chestnut sandy loam and chestnut clayey loam	6	3	2	5	1	2
Meadow-gray irrigated and meadow solonchak-like with meadow-swampy	4	4	5	5	2	2
Gray-brown desert sandy loam and sands	4	3	4	4	3	5
Gray-brown desert sandy loam and moist sands	10	6	8	9	4	8
Alluvial-meadow and meadow-gray irrigated	1	2	3	3	2	5
Mountain chestnut and mountain chernozems	7	2	2	4	0	2

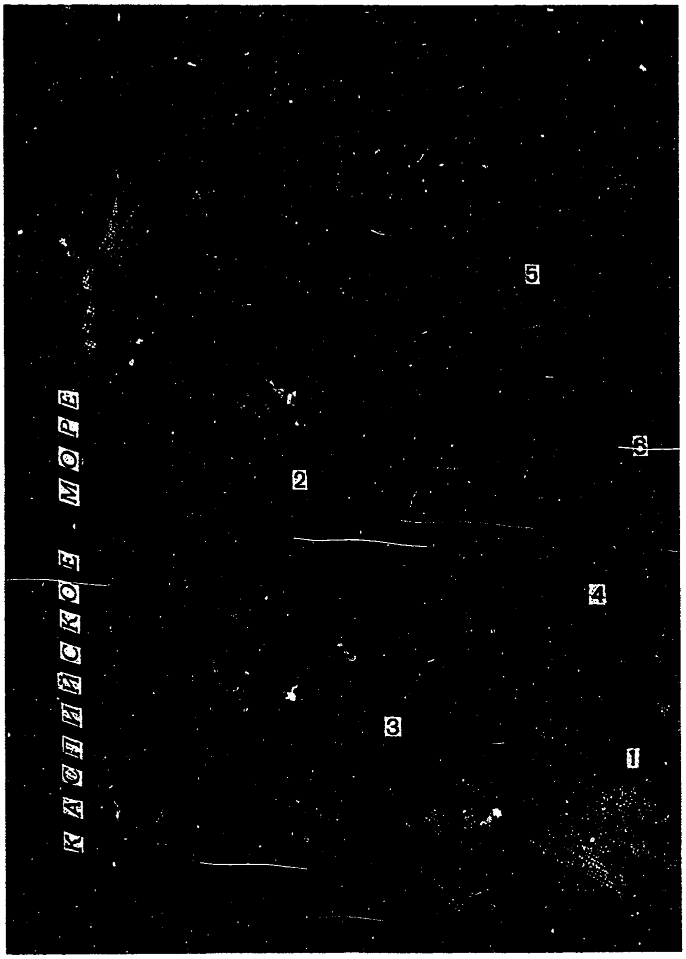


Fig. 36. Color space photograph synthesized in natural colors. Multizonal survey of territory of Tyub-Karagan Peninsula from "Soyuz-12" spaceship made in September 1973. Soils: 1) chestnut; 2) gray-brown solonchak-like; 3) gray-brown solonetz-like; 4) gray-brown solonchak-like eroded soils with bedrock outcrops; 5) solonchaks; 6) sands.

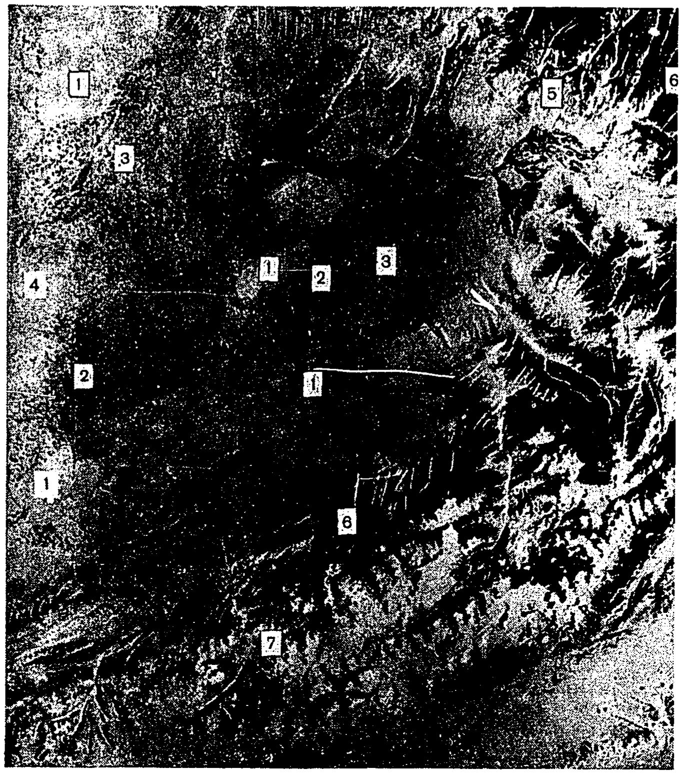


Fig. 37. Space photograph of the Fergana valley obtained from the ERTS-1 in the spectral zone 0.6-0.7μ m and interpretation of the soil cover from it. Survey time -- summer. 1) typical gray soils, light gray soils and meadow-brown soils of Tertiary highlands; 2) irrigated gray soils and meadow-gray soils; 3) irrigated meadow gray soils and meadow boggy soils; 4) gray soil sands, solonchaks and meadow soils; 5) mountain gray soils; 6) mountain cinnamon soils; 7) mountain meadow-steppe soils.

An analysis of the photoimage of the soil cover on these space photographs indicated that mutually supplementing results (Table 41) were obtained when using three spectral zones: 0.5-0.6, 0.6-0.7 and 0.8-1.1μm.

From a space photograph taken in the zone 0.6-0.7 μ m we reliably interpreted the Fergana valley, surrounded by mountain ranges. In the mountains it is easy to see erosional dissection of individual slopes and the valleys of mountain rivers. Here there was formation of mountain gray soils, mountain cinnamon and mountain meadow-steppe soils, whose gradual replacement

[redacted]

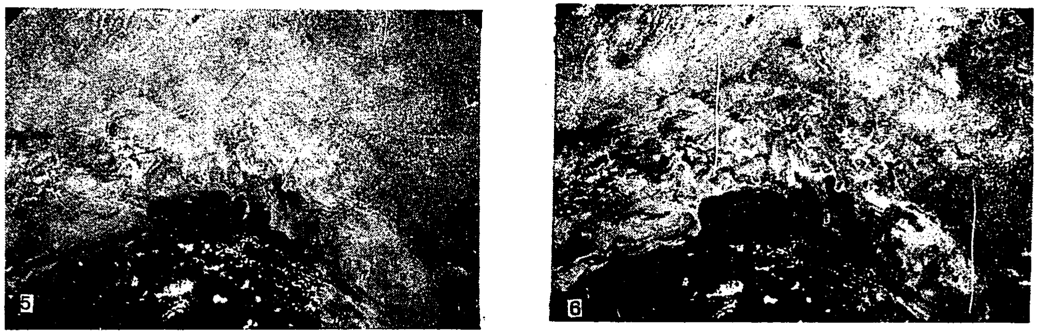


Fig. 38. Multizonal space photographs of Caspian area obtained with MKF-6 camera from "Soyuz-22" spaceship ("Raduga" experiment). Survey time -- autumn. Spectral zones: 1) blue; 2) green; 3) orange; 4) red; 5)-6) IR.

with altitude results in a vertical zonality of the soil cover in the analyzed territory.

South of the Fergana valley the high-mountain part of the Alayskiy Range with mountain meadow-steppe soils is masked by clouds and is not interpreted from the photograph. Mountain cinnamon soils are represented by a dark gray tone where there are a great many short ridges dissected by erosion. In the lower zone there are mountain gray soils which on a space photograph have a light gray and gray tone. This is the territory most deeply dissected by erosion, showing up clearly on the photograph.

The next zone of of undulating foothills (adyry, foothill plains and also depressions between ridges) consists of typical gray soils, light gray soils and gray-brown soils. Their surface is intersected by dry gullies, ravines and many rivers forming with the emergence of alluvial cones into the valley. On a space photograph these soils are represented by a light gray tone of a uniform pattern. A somewhat greater detail of the photoimage of these soils with respect to differences in moistening of the surface and its dissection is visible on space photographs taken in the zones 0.5-0.6 and 0.8-1.1μm.

The irrigated zone of the Fergana valley stands out very sharply from the remaining mountainous and foothill parts due to the mottled multifield pattern of the photoimage of a gray tone with dark small rectangles of an irregular configuration. This is a typical reflection of the agricultural use of lands in this particular territory, for which a cotton-alfalfa crop rotation is characteristic. Predominating gray and light gray tones are characteristic for the image of cotton fields on irrigated gray soils, meadow-gray soils and meadow-boggy soils. Small rectangles of an irregular configuration of a dark tone correspond for the most part to the image of fields occupied by alfalfa and also gardens. From the photoimage pattern it is easy to interpret the alluvial cones of rivers on which irrigated gray soils and meadow-boggy soils are interpreted from the darker general image background of the irrigated zone of the Fergana valley. In the central part of the valley, adjacent to the western frame of the space photograph, it is easy to see an area with a light gray tone with a uniform pattern corresponding to the image of gray soil sands and meadow solonchaks.

With respect to the general nature of the photoimage and the degree of interpretability of the soil cover the considered space photograph in the zone 0.6-0.7μm is close to a photograph obtained in the range 0.5-0.6μm. Among the characteristics of this photograph we note a better contrast in the image of irrigated meadow-gray soils and meadow-bog soils.

A space photograph in the zone 0.8-1.1μm is characterized by poor detail for mountain regions and a poorer contrast between the irrigated part of the Fergana valley and the foothills. The fields occupied by alfalfa and gardens appear on this photograph in a light tone, less clearly conspicuous against the general gray image background of fields occupied by cotton.

In addition, the hydrographic network -- rivers and reservoirs -- is very clearly visible on this photograph. The joint use of three space photographs taken in different spectral zones made it possible to obtain the most complete and objective information on the soil cover of the Fergana valley.

Th eastern part of the Fergana valley and the mountain ranges surrounding it were photographed from the "Soyuz-22" while carrying out the "Raduga" multizonal space experiment in mid-September 1976 (original scale of photographs about 1:2,000,000). These photographs and a soil map of the territory at a larger scale were used in studying the interpretability of the soil cover in six zones of the electromagnetic spectrum: 0.48, 0.54, 0.60, 0.66, 0.72 and 0.82μ m. In the course of our investigations the collected data were compared with the results of interpretation of the analyzed territory from multispectral photographs from the ERTS. The results of the comparative analysis revealed the following.

In the zone 0.48μ m there was a better image contrast between the mountainous part of the territory with mountain cinnamon and mountain-steppe soils, on the one hand, and gray soils and gray-brown soils, soils of the foothills and eroded highlands, on the other. In all four zones of the visible part of the spectrum, but with particular contrast in the red (0.66μ m) zone, there was a boundary contrast between the unirrigated gray soils (light gray tone) and the irrigated sectors of gray soils and meadow-gray soils (dark gray tone). In the red zone of the spectrum it is also easier to see the difference between old and new irrigated lands.

In all four zones (0.48, 0.54, 0.60 and 0.66μ m) cotton fields appeared gray or dark gray and plowed fields corresponded to a light gray, almost white tone due to a low content of humus and a high content of carbonates in the upper cultivated horizons of gray soils. The most inexpressive image of the soil cover was obtained on a photograph in the near-IR zone (0.72 μ m), except for individual more moistened sectors of irrigated gray soils and water bodies. On a photograph in the IR zone (0.82μ m) it was easy to see (dark gray, almost black tone) water bodies. Cotton fields had a light gray and gray tone; plowed fields had a light gray tone. On a photograph in the IR zone within areas of irrigated soils there is a considerably greater differentiation on the basis of tonality (depending on soil moistening) in comparison with photographs in the visible zone of the spectrum.

A comparison of these interpretation results with data obtained from the ERTS satellite revealed a difference in the photoimage of irrigated soils and fields of cotton in dependence on the different survey seasons (late June in one case and mid-September in another). In addition, unirrigated soils -- gray soils and mountain cinnamon soils -- had a similar image. In general, the soil-vegetation cover on multizonal photographs taken from the "Soyuz-22" showed up more differentiated than on the multispectral photographs of the ERTS satellite.

On multizonal space photographs taken from the ERTS satellite in the region of the Tsimlyanskoye Reservoir it is easy to see the territory of the steppe zone, considerably exploited in agricultural respects. The survey was made on 11 June 1973. Our investigations of the space photographs indicated the following.

The photographs are characterized by a mottled square-rectangular pattern of different tone corresponding to the image of fields with different agricultural crops. This pattern is especially clearly expressed on a photoraph. A photograph in the zone 0.5–0.6 μm is characterized by a poor image contrast of the fields. In the IR zone (0.7–0.8 and 0.8–1.1 μm) the photographs had a similar image and in the work only the latter of these was analyzed. In the IR zone (0.8–1.1 μm) all the fields which in the zones 0.5–0.6 and 0.6–0.7 μm had a dark gray and gray tone, became light gray, almost white in tone. River channels and sectors of irrigated soils are interpreted due to their almost black tone against the general light gray image background, standing out very sharply. On photographs in the visible zone (0.5–0.6 and 0.6–0.7 μm) river channels and irrigated fields are not interpreted. With respect to photoimage they are similar to the surrounding territory.

On photographs taken in the zone 0.6–0.7 μm it is easy to trace the different exploitation of southern chernozems, chestnut and light chestnut soils for the purposes of agricultural production. The nature of agricultural exploitation was taken into account in the interpretation of the soil cover from space photographs. It should be noted that it is difficult to interpret the soils of this region through the mottled image of the fields. Exceptions were alluvial meadow (dark gray tone in the zone 0.6–0.7 μm) and alluvial meadow solonetzlike soils (light gray and gray tone). In all zones there was reliable determination of areas of chestnut sandy loam and consolidated sands.

Thus, our experience in the use of multizonal space photographs obtained from the ERTS for study of the soil cover of the steppe and desert zones indicated the following.

In the interpretation of the desert zone space photographs in the zone 0.5–0.6 μm for the early summer survey period were successfully used in discriminating areas of irrigated meadow-gray and meadow-bog soils amidst irrigated gray soils.

Photographs in the zone 0.6–0.7 μm for the territory of the steppe and desert zones are the most contrasting with respect to the photoimage of the soil cover and areas of agricultural crops.

On photographs in the zone 0.8–1.1 μm it is easy to see river channels along which there is reliable determination of alluvial soils; in the steppe zone amidst unirrigated areas of cultivated lands there is reliable interpretation of irrigated fields on these photographs.

In general, for objective interpretation of the soil cover and agricultural crops it is necessary to use space photographs in all three considered zones of the electromagnetic spectrum.

Interpretation of Soils and Vegetation from Multizonal Space Photographs from "Soyuz-22"

An experimental flight of the "Soyuz-22" spaceship took place during the period 15-23 September 1976 under the program of cooperation among the socialist countries in the field of use of space vehicles for study of the earth's natural resources. During the flight of the flier-cosmonauts V. F. Bykovskiy and V. V. Aksenov a survey was made of the earth's surface using the MKF-6 multispectral camera. The idea of the new multizonal method was based on the possibility of measuring the intensity of radiation of features on the earth's surface, including soils and agricultural crops, simultaneously in several narrow spectral zones.

On the basis of study of the spectral characteristics of 2,000 surface features the specialists of the Space Research Institute USSR Academy of Sciences, who participated in the development of the MKF-6 camera, for the survey selected six spectral zones (four in the visible region, two in the IR spectral region). By means of a new instrument, developed by specialists of the USSR and GDR, the MSP-4 synthesizer, multizonal black-and-white photographs can be synthesized into an integrated color image. The scale of the original photographs is ~1:2,000,000. The high resolution of the photographs makes it possible to use them to determine and analyze sectors measuring 1 hectare. In order to improve the interpretation of the soil cover it is desirable to use photographs enlarged 4-5^x in comparison with the original (measuring 55 x 80 mm). With an enlargement 5^x the image quality of the soils does not worsen.

In the diagnostic interpretation of soils from multizonal space photographs from the "Soyuz-22" for the territory of the semidesert and forest zones we used (for the investigated region) soil maps at medium and small scales.

The objective of the investigations included, first of all, a study of the possibilities of determining soils from photographs of different spectral zones and determining the most promising of these, and second, use of multizonal photographs for the purposes of soil mapping and improving existing soil maps.

One of the sectors surveyed using a multizonal camera covered the territory of southeastern Kazakhstan — the northeastern slopes of the Dzhungarskiy Alatau and the tectonic depression with Lakes Alakol' and Sasykkol'. In the analysis of the soil cover use was made of multizonal double negatives, double positives, original space photographs and those enlarged 3^x.

On the multizonal photographs (with particular contrast in the red zone) it was possible to interpret the upper parts of mountain ranges with snowfields and mountain meadow alpine and subalpine soils. The northern, more low-lying ranges of the Dzhungarskiy Alatau consisted of mountain leached and podzolized chernozems, whereas their marginal parts were characterized by mountain chestnut soils. The slopes were incised by a great number of relatively short mountain rivers. As a result, on the photographs the photoimage of the mountainous part has a complex structured-dendritic pattern.

Intermont basins occupied by chernozems and chestnut soils were successfully interpreted from the photographs. The mountains drop off (along a fault) sharply, linearly, in a northward direction, in the direction of the Alakol'skaya depression. The surface of the depression consists of a thick stratum of unconsolidated alluvial, proluvial, lacustrine and eolian deposits of Quaternary age. A complex soil cover was formed on them with a transition from chestnut soils in the foothill sector to gray-brown desert and gray soils. A considerable area of the depression is occupied by a sandy desert. In the neighborhood of the lake there are meadow-gray soils, meadow solonchak soils, solonetz and solonchak soils and meadow swamp soils on the photograph having a complex spotty image pattern of different tonality.

In places where mountain rivers emerge onto the plain, from the image form on the photographs it is easy to interpret present-day and more ancient alluvial fans with meadow-gray soil irrigated areas. The marginal part of alluvial fans has a mottled, spotty pattern with serrated edges. Meadow solonchak-like, meadow-swampy, meadow solonchak-like solonetz soils and meadow solonchak soils were formed here.

An investigation of the soil cover of the territory of southeastern Kazakhstan on the basis of multizonal photographs indicated the following.

Photographs in different spectral zones mutually supplement one another with respect to better and more complete representation of the soil cover. Table 42, for different spectral zones, gives data on the boundary contrast of soils of the analyzed territory with respect to solonetz-solonchak soils, on the photographs having an almost white tone of the photoimage. Table 43 gives the interpretability of a number of bordering soils on multizonal photographs. An analysis of the photographs and the data in these tables show that in the blue zone the soil cover is interpreted well, showing up with good contrast. The difference between light chestnut sandy loam and chestnut soils, gray-brown desert and moist sands, mountain chestnut and mountain chernozem soils is apparent. On photographs in the red zone it is easier to see the difference between the mountain ranges and the leveler sectors of slopes; there is a greater contrast of meadow-swampy soils, differences in soils of sandy deserts, etc. Only on an IR photograph amidst meadow-gray irrigated soils was there a clear determination of the areas of alluvial-meadow soils and lake sectors could be detected amidst meadow-swampy soils.

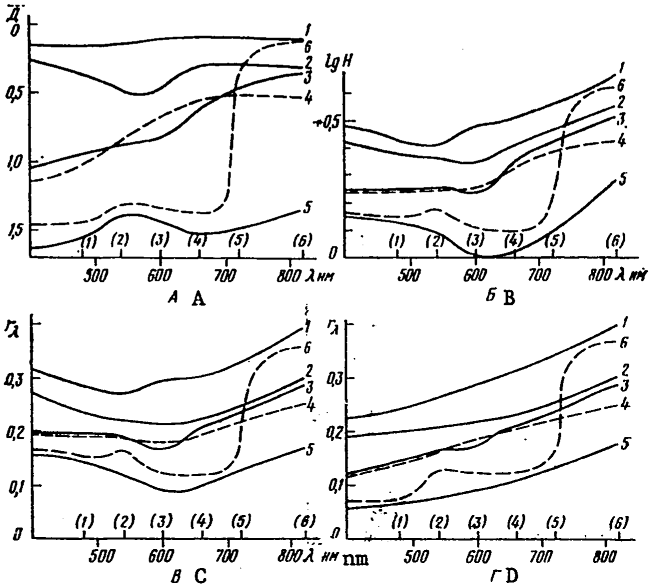


Fig. 39. Diagnostic spectral curves of soils in Caspian area obtained from multizonal space photographs. Survey made with MKF-6 camera from "Soyuz-22." A) from contact prints; B) from double negatives, reduced to real exposure, taking into account optical wedge correction; C) from double negatives, with allowance for optical wedge correction, solar altitude, distance of analyzed soil from center of photograph and true exposure for each survey channel; D) from double negatives with allowance for all corrections (enumerated above) and atmospheric correction. Soils: 1) saline solonchaks; 2) brown desert-steppe solonchak-like sandy loam soils on greenish-gray new Caspian deposits; 3, 4) brown desert-steppe solonetz-like sandy-loam soils on red-brown sands; 5) alluvial meadow-swampy solonchak-like soils; 6) swampy coastal solonchak-like soils (with overgrowths of reeds). (1), (2), (3), (4), (5), (6) are spectral zones.

An analysis of the reliability of interpretation of the soil cover from multizonal space photographs shows that the interpretability of more than 60% of the soil units is better than average on photographs in the blue, red and IR (820 nm) spectral zones (Table 44). The lowest interpretability of soil cover was noted on photographs in the IR (720 nm) zone: on these photographs more than 80% of the soil units were poorly determined or not interpreted at all. The results of interpretation of soils in the analyzed territory from space photographs were finalized in the form of a sample soil map and were compared with the available map.

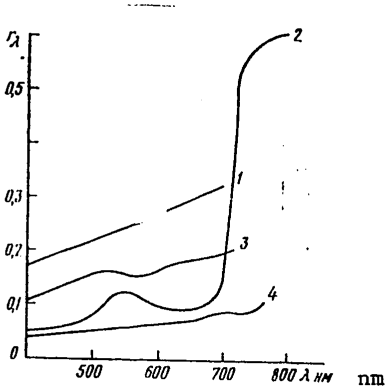


Fig. 40. Spectral soil reflection curves (according to Ye. L. Krinov) obtained under surface conditions: 1) sand (dry); 2) reeds (bright green), swampy soil; 3) sandy loam (dry) soil; 4) swampy (very moist) soil.

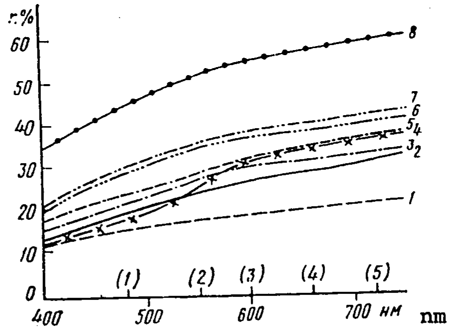


Fig. 41. Spectral soil reflection curves for samples from Caspian Lowland (Ural and Emba interfluve). Soils: 1) alluvial meadow-swampy solonchak-like clayey loam; 2) alluvial meadow solonchak-like clayey loam; 3) meadow solonchak-like solonetz soils; 4) brown desert-steppe solonetz-like sandy loam soils on red-brown sands; 5) meadow solonchak-like sandy loam soils on greenish-gray new Caspian deposits; 6 and 7) brown desert-steppe solonchak-like sandy loam soils on greenish-gray new Caspian deposits; 8) saline solonchaks. (1), (2)... spectral zones for survey with MKF-6 camera.

Still another set of six black-and-white multizonal space photographs taken while carrying out the "Raduga" experiment was investigated for Western Kazakhstan -- southeastern part of the Caspian Lowland. In the diagnostic interpretation of soils use was made of medium-scale soil maps of the

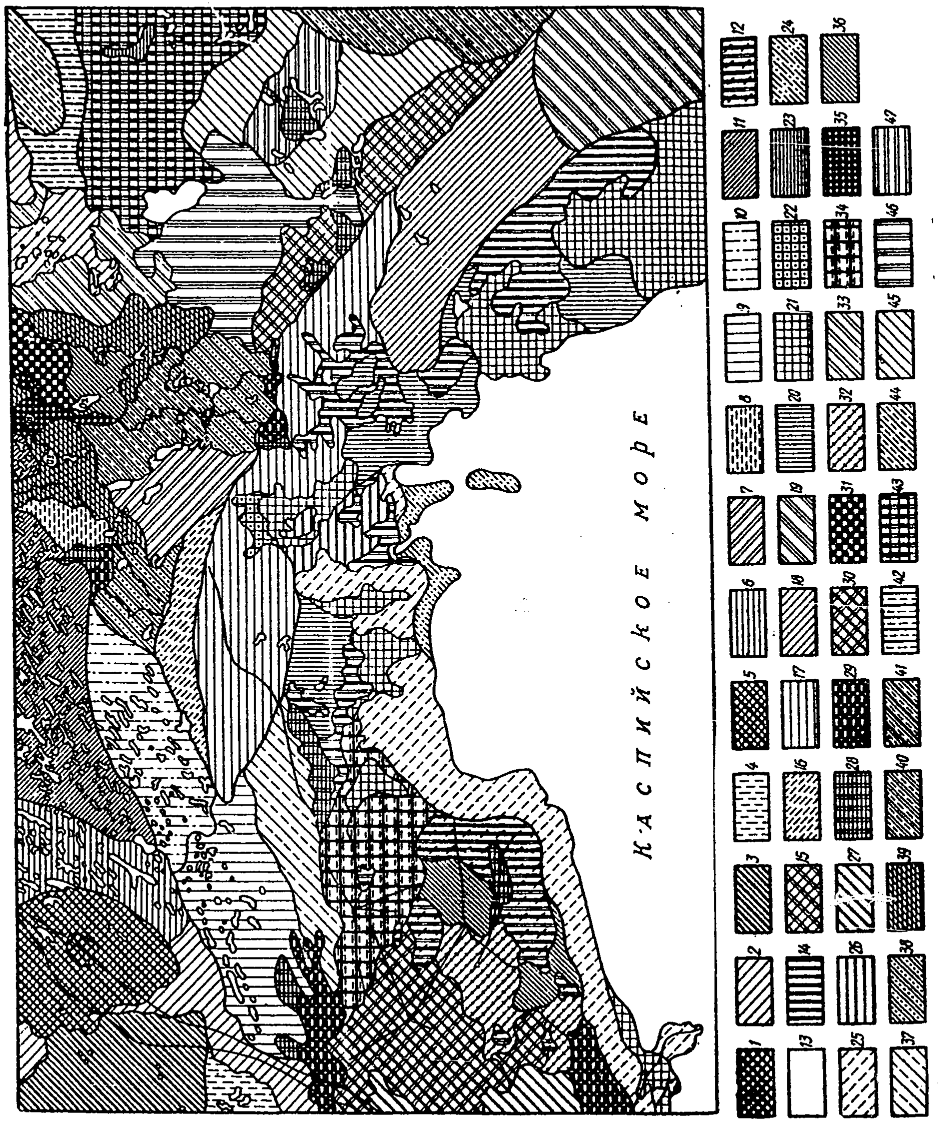


Fig. 42. Interpretation of the soil cover in the Caspian area from multizonal black-and-white space photographs and color synthesized photograph.

KEY TO FIGURE 42

Soils: 1) brown desert-steppe solonetz-like; 2) brown desert-steppe solonetz-like and salina solonchaks; 3) brown desert-steppe solonetz-like, solonetz and salina solonchaks; 4) brown desert-steppe solonetz-like, solonetz and salina solonchaks (20%); 5) brown desert-steppe solonetz-like, saline solonchaks and solonetz; 6) brown desert-steppe solonetz-like, saline solonchaks (50%), solonetz; 7) brown desert-steppe solonchak-like, brown desert-steppe solonetz-like and saline solonchaks; 8) brown desert-steppe solonchak-like and saline solonchaks; 9) brown desert-steppe solonchak-like, solonetz and salina solonchaks; 10) salina solonchaks, brown desert-steppe solonchak-like and solonetz; 11) salina solonchaks, solonetz and brown desert-steppe solonchak-like; 12) meadow solonchaks; 13) salina solonchaks; 14) coastal solonchaks; 15) meadow solonchak-like, brown desert-steppe solonchak-like and salina solonchaks; 16) meadow solonchak-like and meadow solonetz; 17) meadow solonchak-like, meadow solonetz and salina solonchaks; 18) meadow solonchak-like, watershed meadow and meadow-swampy solonchak-like and salina solonchaks; 19) meadow solonchak-like, watershed meadow solonchak-like and salina solonchaks; 20) meadow solonchak-like coastal and coastal solonchaks; 21) coastal solonchaks and meadow coastal solonchak-like; 22) coastal solonchaks, meadow solonetz and meadow solonchak-like; 23) meadow-swampy solonchak-like; 24) swampy coastal solonchak-like; 25) meadow coastal solonchak-like and swampy coastal solonchak-like; 26) meadow and swampy coastal solonchak-like and coastal solonchaks; 27) alluvial meadow solonchak-like; 28) alluvial moist-meadow solonchak-like; 29) alluvial meadow-swampy solonchak-like; 30) alluvial meadow, moist meadow and meadow-swampy solonchak-like; 31) alluvial moist-meadow and meadow-swampy solonchak-like; 32) alluvial meadow solonchak-like and moist meadow solonchak-like; 33) alluvial meadow and moist meadow solonchak-like and solonchaks; 34) alluvial meadow-swampy solonchak-like and moist-meadow solonchak-like; 35) alluvial meadow and meadow-swampy solonchak-like; 36) alluvial meadow and meadow-swampy solonchak-like and solonchaks; 37) alluvial meadow solonchak-like, brown desert-steppe solonchak-like, meadow solonetz and solonchaks; 38) alluvial meadow solonchak-like (20%), brown desert-steppe solonetz-like and solonchaks; 39) alluvial meadow solonchak-like (20-30%), brown desert-steppe solonetz-like and solonchaks; 40) alluvial meadow solonchak-like (more than 30%), brown desert-steppe solonetz-like and solonchaks; 41) sands and salina solonchaks; 42) sands and brown desert-steppe solonchak-like; 43) sands, brown desert-steppe solonchak-like and salina solonchaks; 44) sands, salina solonchaks and brown desert-steppe solonetz-like; 45) brown desert-steppe solonchak-like, salina solonchaks with participation of sands (10%); 46) salina solonchaks, brown desert-steppe solonchak-like with participation of sands (10%); 47) salina solonchaks with participation of sands (10%).

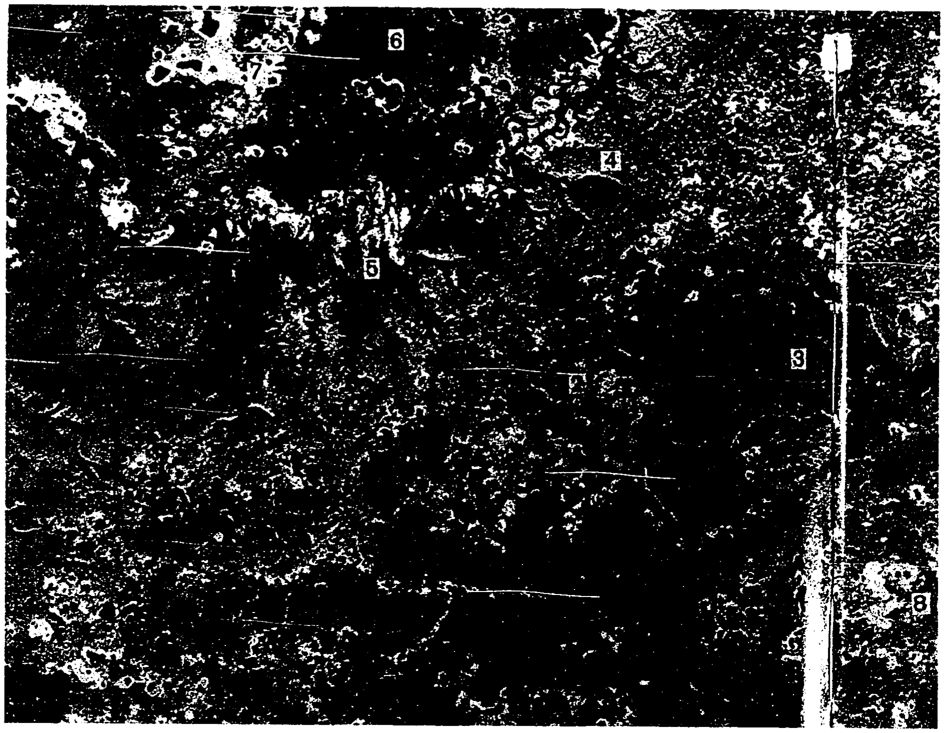
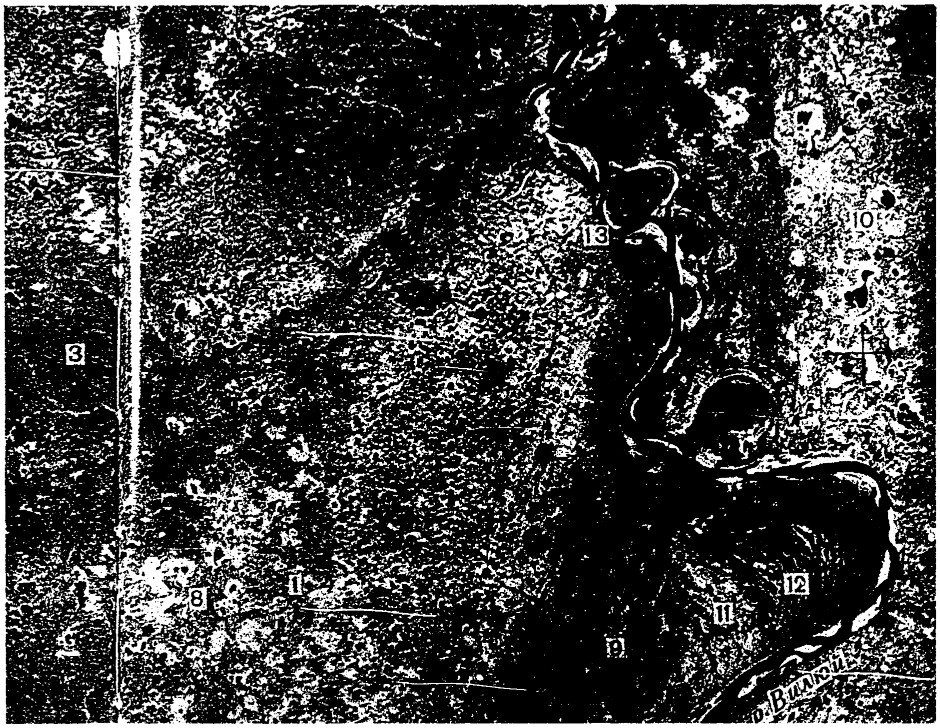


Fig. 43. Color synthesized space photograph of territory of poorly drained watersheds of Central Yakutian Plain and floodplain of Vilyuy River taken from "Soyuz-22" and interpretation of soil cover from it (autumn survey period 1976): 1) straw-colored taiga solodized permafrost heavy clayey loam soils, taiga solods, meadow-swampy permafrost (up to 90%) and lenses of vein ice under moist larch taiga; 2) straw-colored taiga solodized permafrost heavy clayey loam soils, taiga solods, meadow-swampy permafrost (40-50%) and lenses of vein ice under moist larch taiga; 3) straw-colored taiga solodized permafrost clayey loam soils, straw-colored taiga permafrost, soddy-meadow and meadow-swampy permafrost under moist larch taiga; 4) straw-colored taiga permafrost light clayey loam and sandy loam soils and soddy-meadow permafrost soils under larch taiga; 5) straw-colored taiga permafrost soils with participation of eroded and soddy-meadow permafrost soils under pine larch taiga; 6) soddy forest permafrost soils, straw-colored taiga solod permafrost soils, meadow-swamp permafrost soils under pine-larch taiga; 7) soddy forest permafrost sandy soils, straw-colored taiga solodized



[Caption to Fig. 43 continued]

permafrost, meadow-chernozem, taiga solods, meadow-swampy permafrost soils and sands under pine-larch taiga; 8) meadow-swampy permafrost taiga solods ("alasy"); 9) straw-colored taiga solodized permafrost light clayey loam soils, meadow-chernozem solonetz-like permafrost soils and swampy permafrost soils; 10) straw-colored taiga solodized permafrost, taiga solods, meadow-swampy permafrost soils and spots of sulfate-soda solonchaks; 11) alluvial-meadow, meadow solodized and meadow-swampy permafrost soils; 12) alluvial-meadow and meadow-swampy permafrost soils; 13) alluvial primitive sandy soils.

Kazakh SSR and field reconnaissance investigations were made. The space survey was made at the original scale (about 1:2,000,000) on 12 September 1976. In the soil cover analysis use was made of double negatives and double positives, original (Fig. 38) space photographs enlarged by a factor of three, as well as an enlarged synthesized color photograph obtained from four zones (0.48, 0.54, 0.66, 0.82 μm) with an MSP-4 instrument.

Table 44

Evaluation of Reliability of Interpretation of Soil Cover from Multizonal Space Photographs (Positive Film) of Southeastern Kazakhstan. "Raduga" Experiment. Survey Time 17 September 1976

Степень дешифрируемости почв (в относительных единицах) 1	2 Количество почвенных контуров в зонах спектра (λ в нм)											
	синей (480) 3		зеленой (540) 4		оранжевой (600) 5		красной (660) 6		7 инфракрасной			
									(720)		(820)	
	ед. 8	%	ед.	%	ед.	%	ед.	%	ед.	%	ед.	%
9 Контуры не дешифрируются или определяются сомнительно (0—2)	9	18,7	9	18,7	8	16,7	9	18,7	13	28,1	6	12,5
10 Слабая (3—5)	8	16.7	9	18,7	11	23,0	9	18,7	26	54,2	12	25,0
11 Средняя (6—10)	14	29,2	23	48,0	21	43,6	20	41,7	8	18,7	24	50,0
12 Хорошая (11—20)	15	31,2	7	14,6	8	16,7	8	16,7	—	—	6	12,5
13 Резкая (21—30)	2	4,2	—	—	—	—	2	4,2	—	—	—	—
14 Всего контуров	48	100	48	100	48	100	48	100	48	100	48	100

KEY:

1. Degree of interpretability (in relative units)
2. Number of soil units in spectral zones (λ in nm)
3. Blue
4. Green
5. Orange
6. Red
7. IR
8. Units
9. Units not interpreted or interpreted doubtfully
10. Weak
11. Medium
12. Good
13. Sharp
14. Total number of units

We obtained a considerable effect in the study of soil and agricultural resources from color and synthesized space photographs due to the possibility of detecting from the color on them those natural features which are necessary for analysis. For example, from a space photograph synthesized using the MSP-4 instrument for the Caspian area (interfluve of the Ural and Emba) it was easy to discriminate lands of different quality.

The first and second terraces of the Caspian Sea are interpreted first. The first lower flat sea terrace of the Caspian consists of recent new Caspian deposits of a greenish-gray color with a great amount of coquina. Ground water of a magnesian-sodium chloride salinization with a mineralization of 150-180 g/liter of dry residue was situated at a depth of 0.5-3 m. The soils are weakly developed. Extensive areas of land were occupied by sodium chloride coastal solonchaks on the south adjoining the Mertvyy Kultuk salina, constituting an extensive sandy-salina plain -- the former bottom of Zaliv Komsomolets. The lands of the first terrace of the Caspian were covered with a thin wormwood-Russian thistle vegetation and in economic respects constitute pastures of low productivity.

Table 44a

Coefficients of Spectral Brightness of Soils (Blue Zone)

Почвы 1	С учетом атмосферы 2	Без учета атмосферы 3		Разность спектральных коэффициентов 6
		по Е. Л. Кринову 4	по Ю. С. Толчельникову 5	
7 Солончак	0,32	—	0,25	0,07
8 Бурая пустынно-степная супесчаная на зеленовато-серых отложениях	0,26	—	0,17	0,09
9 Бурая пустынно-степная супесчаная на красно-бурых отложениях	0,20	0,12	0,11	0,08—0,09
10 Аллювиальная лугово-болотная	0,15	0,04	0,04	0,11
11 Болотная (с зарослями камыша)	0,16	0,05	0,05	0,11

KEY:

1. Soils
2. With allowance for atmosphere
3. Without allowance for atmosphere
4. According to Ye. L. Krinov
5. According to Yu. S. Tolchel'nikov
6. Difference in spectral coefficients
7. Solonchak
8. Brown desert-steppe sandy loam on greenish-gray deposits
9. Brown desert-steppe sandy loam on red-brown deposits
10. Alluvial meadow-swampy
11. Swampy (with overgrowths of reeds)

The lands of the second terrace of the Caspian reveal a sharp differentiation of relief, soils and vegetation. There is clear interpretation of sectors with well-developed crested relief of so-called "berovskiye" hills. The peaks and slopes of crests and ridges of a northeasterly direction consist of brown desert-steppe solonchak-like soils with wormwood-mixed grass associations; in the depressions there are numerous solonchaks (salinas).

Two large anomalies can be seen against a general greenish-blue photoimage of brown desert-steppe solonchak-like soils, solonetz soils and solonchaks, formed on greenish-gray material of light mechanical composition. It is easy to see the annular Dossorskaya structure, for the first time discovered from space photographs. In the relief it constitutes a slightly uplifted undulating plain with brown desert-steppe soils, frequently solonetz-like, formed on red-brown sandy material. The second major anomaly is associated with the image of sectors of reddish-brown sandy soils of the Prikaspiyskiye Karakumy.

Table 45

Evaluation of Reliability of Interpretation of Soil Cover from Multizonal Space Photographs (Positive Film) of Southeastern Part of Caspian Lowland "Raduga" Experiment. Survey Time 12 September 1976

Степень дешифрируемости почв (в относительных единицах) 1	2 Количество почвенных контуров в зонах спектра (в λ нм)											
	синей (480) 3		зеленой (540) 4		оранже-вой (600) 5		красной (660) 6		7 инфракрасной			
									720		820	
	ед. 8	%	ед.	%	ед.	%	ед.	%	ед.	%	ед.	%
9 Контуры не дешифрируются или определяются сомнительно (0—2)	4	8	1	2	2	4	2	4	7	14	—	
10 Слабая (3—5)	8	16	5	10	10	20	9	18	33	66	13	26
11 Средняя (6—10)	15	30	25	50	24	48	22	44	10	20	34	68
12 Хорошая (11—20)	16	32	17	34	12	24	16	32	—	—	3	6
13 Резкая (21—30)	7	14	2	4	2	4	1	2	—	—	—	—
14 Всего контуров	50	100	50	100	50	100	50	100	50	100	50	100

KEY:

1. Degree of interpretability (in relative units)
2. Number of soil units in spectral zones (in λ nm)
3. Blue
4. Green
5. Orange
6. Red
7. IR
8. Units
9. Units are not interpreted or are determined doubtfully
10. Weak
11. Medium
12. Good
13. Sharp
14. Total number of units

On a space synthesized photograph on the basis of the meander-ox-bow lake and delta form of a reddish-cinnamon, greenish-brown and almost black color there is reliable determination of alluvial-meadow and meadow-swampy floodplain and delta soils, of the different degree of salinization of soil along the Ural and Emba soils. The vegetation cover here is represented by solonchak-wormwood-mixed grass associations, grass-mixed grass and meadow vegetation with the participation of sedge, reedgrass, quack grass and sweetclover, and on low-lying meadows with excess moistening --

cattails, reeds, rushes. These lands constitute the most valuable pasture and haying resources of this region.

In the coastal sector of lands of the ancient Ural delta a band of a red-cinnamon color (width 4-5 km and extending eastward from Gur'yev up to 100 km) there were meadow and meadow-swampy saline coastal soils with overgrowths of reeds, constituting an important area for industrial exploitation.

In our investigations of the soil cover of the Caspian territory from multizonal black-and-white space photographs we used the visual-instrumental method for the processing of photographs with the use of the "Macbeth" optical-electronic densitometer. Using this instrument, operating in reflection and transmission regimes, repeating each procedure five times, we ascertained the optical densities D (brightness) for the soil image on a series of multizonal photographs and their double negatives.

The "spectral image" curves for soils in the Caspian territory obtained using these materials are given in Fig. 39; the spectral curves of soils obtained from contact multizonal prints are given in Fig. 39A. They have an approximate nature because they do not take into account the differences in light scattering characteristic for each of the spectral zones. Figure 39B shows the curves of spectral brightness of soils in relative units obtained from double negatives, reduced to the real exposure, taking into account the optical wedge correction. The construction of these curves does not require complex computations. They correctly reflect the "spectral image" of each soil, but do not allow their quantitative evaluation. Figure 39C shows curves of the spectral brightness coefficients for soils obtained from double negatives, taking into account the optical wedge correction, corrections for solar altitude, distance of the analyzed soil from the center of the photograph and the true exposure for each survey channel.

An analysis of these curves indicated that for all soils there is a characteristic quantitative spectral image. There is a general rise of the curves from the green to the IR zone, but not so sharply expressed as for vegetation (reeds). In the blue spectral zone some rise in the curves is associated with an increase in atmospheric brightness.

It is known that in a survey from space through the atmospheric layer the brightness of haze is superposed on the brightness of features. The "luminescence" of haze exerts a strong effect on the light-sensitive film layer, especially sharply expressed in the blue spectral zone. In order to take this influence into account and compute the correction for the atmosphere we compared the coefficients of spectral brightness of soils, determined with and without allowance for the atmosphere, using data from a field spectral survey (Table 44a).

Using the data in Table 44a it is possible to determine the mean correction factor (K_a) for the atmosphere -- the spectral brightness of soils (for the blue zone), equal to 0.09.

For light-colored soils (solonchaks, brown desert-steppe soils and others) it is less; for dark-colored soils (meadow-swampy soils, etc.) the influence of the atmosphere was stronger and the coefficient was larger.

Diagnostic spectral curves for soils (Fig. 39D) were constructed with allowance for this correction for the atmosphere and all the above-mentioned corrections (optical wedge, solar altitude, distance of the analyzed soil from the center of the photograph, etc.).

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These spectral curves, obtained as a result of processing of six multizonal films (Fig. 39D), were compared with the spectral curves of some similar soils obtained by Ye. L. Krinov in the field (Fig. 40). Their analysis indicated that the curves for these soils are similar. We note from the peculiarities of these curves that solonchaks and dry sands show up on the photographs in a light tone and have similar spectral curves. However, in the blue zone sands reflect less light and their brightness coefficient is lower. Reeds, according to data published by Krinov, are bright green and their curve in the IR region rises steeply upward; under our conditions (with a survey in autumn) reeds are less bright green and the curve in the IR zone does not rise so high.

The spectral curves for dry sandy loam and very moist swampy soil, obtained under ground conditions and from space, are similar. Thus, we emphasize the point that using multizonal space photographs (with the corrections taken into account) it is possible to obtain diagnostic spectral curves of soils.

An examination of the spectral curves shows that in the blue-green part of the spectrum there is a convergence of the curves for brown desert-steppe solonetz-like soils formed on red-brown sands and alluvial meadow-swampy soils. As a result, on photographs in this zone they show up in a similar dark gray tone. In the red zone the curves for brown desert-steppe soils developed on red-brown material diverge quite clearly from the curves for alluvial meadow-swampy soils, approaching the curves for brown desert-steppe solonchak-like soils developed on greenish-gray new Caspian deposits. As a result, on the photographs for this spectral zone they show up in a gray-light gray tone. The highest spectral brightness coefficient is characteristic for salina solonchaks which on the photographs in all spectral zones have an almost white photoimage tone. These patterns were confirmed in an investigation of soil reflectivities.

Our analysis of the spectral reflectivity of soil samples (Fig. 41) indicated that in the blue-green spectral zone brown desert-steppe soils and sands on reddish-brown deposits have a low reflectivity; their curves are close to the spectral curves for alluvial meadow-swampy soils. In the red spectral zone the reflectivity of brown desert-steppe soils on reddish-brown deposits increases sharply and their spectral curves approach the curves for brown desert-steppe soils formed on greenish-gray deposits. The saline surface crust of solonchaks had the maximum reflectivity.

Thus, due to the joint determination of soil reflectivity and the use of black-and-white multizonal space photographs for the first time it became possible to make a quantitative interpretation of the soils formed on different soil-forming rocks.

An investigation of the photoimage of soils on black-and-white photographs in the IR, red and blue-green spectral zones indicated that only in the IR zone did a gray - dark gray image tone correspond to an extensive area in the region of spring floodings of the Emba River and its numerous distributaries. The discrimination of this area is evidently associated with the presence here of soils with the ground water at a shallow depth. In the IR zone (0.82μm) from the dark gray, almost black tone, it is easy as well to determine moist meadow and meadow-swampy soils. At the same time, individual areas of alluvial-meadow and delta soils (for example, the Emba River) on this photograph are interpreted poorly or are not interpreted at all, although they are easy to make out on photographs in the visible, especially the blue spectral zone. These soils are covered by meadow vegetation, which in the IR zone appears in a light tone, similar to the image of the surrounding solonchaks and solonchak-like soils.

The most nonexpressive, low-contrast photoimage of the soil cover was obtained using photographs in the IR (0.72μm) zone.

A comparative analysis of the photoimage of a color synthesized photograph and black-and-white photographs of individual zones indicated that on a synthesized photograph in the more easily interpreted color range there was reflection of all soil units of multizonal black-and-white photographs. At the same time, only on a synthesized photograph on the basis of a red-brown and yellow-brown color is there clear interpretation of soil areas covered with a natural grassy vegetation. The greater the projective covering of the soil surface and the brighter the green color of the vegetation in the terrain, the brighter is the red color of its image on the synthesized photograph. On black-and-white photographs from the gray range of tones it is difficult to discriminate areas of these soils from soils poorly covered with vegetation and from soils without vegetation.

Accordingly, in the areal interpretation of soils the greatest effect is from synthesized photographs. They are also effective for the purposes of genetic interpretation of the soil cover, although individual data (such as the difference in soils formed on different rocks, etc.) can be obtained only in an analysis of black-and-white multizonal space photographs.

The results of interpretation of soils from black-and-white multizonal and color synthesized space photographs were finalized in the form of a sample soil map (Fig. 42) which shows the characteristics of the soil cover in the Caspian area.

A computer analysis of the photoimage of the soil cover in the Caspian area on space photographs in the blue, red and IR spectral zones by means of the "Kvantimet-720" instrument made it possible to obtain maps of the levels of gray tone which were used for compiling a soil map of this region which was detailed and objective.

In the blue and red spectral zones the darkest tone was characteristic of areas (similar in form) of alluvial moist meadow and meadow-swampy solonchak-like soils and also coastal meadow and swampy solonchak-like soils. In these two zones the use of computer interpretation revealed a considerable differentiation of the gray tone levels in areas of alluvial soils along the Emba and Ural Rivers. However, whereas on photographs in the IR zone in the Emba River region no high percentage of areas with a gray tone was discovered in the soil cover image, in the ancient delta part of the Ural River it was considerable and similar to the image of areas on photographs taken in the red zone.

In the red and IR spectral zones the lightest image was characteristic of areas (similar in form) of salina and coastal solonchaks. On photographs in the IR zone a considerable percentage of the soil cover was associated with a reflection of spottiness of a darkish-gray tone -- the image of meadow solonchak-like soils.

On the photographs in the zones to be analyzed, the clouds, which make difficult the interpretation and distort the computer analysis of the soils, were represented by areas of a light tone, similar to solonchaks, whereas the shadows from them are represented by areas of a dark gray tone, similar to the image of meadow-swampy soils.

Our evaluation of the reliability of interpretation of the soil cover in the southeastern part of the Caspian Lowland from multizonal space photographs indicated that in the visible zone more than 75-80% of the soil units are determined with an accuracy above the average (in the blue zone -- 76, green zone -- 88, orange -- 76, red -- 78%). In the IR (0.72μm) zone 80% of the units are not interpreted or are determined poorly, but in the zone 0.82μm 68% of the soil units have an average interpretability relative to solonchaks (Table 45).

In order to study the possibilities of interpretation of soils and plantings of agricultural crops, in addition to multizonal space photographs of the dry steppe zone we analyzed photographs of other natural zones. As an example, we will examine two sectors of territory of a forest zone taken during the period of carrying out of the "Raduga" multizonal experiment. Synthesized color photographs were used in the analysis.

On a color synthesized photograph taken for analysis it was possible to see a region of Eastern Siberia in the neighborhood of the lower course of the Vilyuy River which is inaccessible for surface study. In the diagnostic interpretation of the soils from this photograph we used medium-scale soil maps of the investigated territory.

In natural respects this is a sector of the Central Yakutian slightly undulating ancient alluvial plain, consisting of strata of sandy-clayey Quaternary deposits. The territory is situated in a permafrost zone with a depth of seasonal freezing and thawing in sandy ground of 3-4 m, in pulverized clayey loams under a larch taiga -- 1.2-1.6 m, in swampy and boggy-peaty soils -- 0.2-0.5 m.

On the poorly drained watershed there is extensive development of vein ice and thermokarst processes with the formation of lacustrine landscapes of a special type, so-called alasy. In such landscapes there are numerous thermokarst depressions formed by collapse, sinking or slumping which arise on the plain surface with the melting through of ice strata. As a result of melting of the ice the central part of such an area is occupied by a lake and the marginal parts by meadow-swampy and meadow vegetation. The depressions in such landscapes are frequently saline. According to the map of types of soil salinization (Yegorov, Bazilevich, 1976), to the north of the Vilyuy River there is sulfate salinization, whereas to the south there is chloride-sulfate salinization with the participation of soda.

In the interpretation of the soil through the direct image of forest and meadow vegetation on the photograph it is easy to trace four natural soil-geographic regions in the investigated territory.

The first occupies the northeastern part of the photograph -- the territory which on the north adjoins the Tyung River, a left-bank tributary of the Vilyuy. Here, on well-drained loosely consolidated sandy deposits is a coniferous taiga -- pine and pine-larch. The soil cover is represented by soddy-forested permafrost sandy and sandy loam soils, straw-colored taiga solodized permafrost soils with participation of semiconsolidated and deflatable sands. There is widespread occurrence of large lake basins with meadow-swampy permafrost, taiga degraded solonetz and meadow-chernozem soils formed along the periphery of lakes. On the photograph the soils of this region are interpreted from the cinnamon-brown image color of the coniferous taiga; areas of a white color correspond to sands. Light concentric bands and circles around lakes correspond to the image of meadow and meadow-swampy soils.

The next natural region includes poorly drained watersheds adjacent to the left bank of the Vilyuy River. This is the central part of the photograph having a green image color. Against this background lakes show up as numerous small spots and dots of a black color; it is easy to see a mass

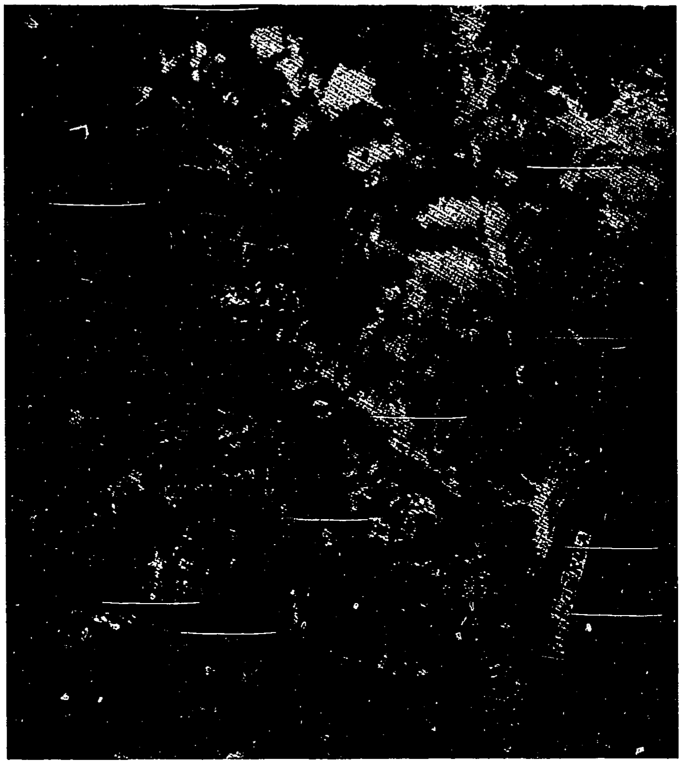

Fig. 44. Color synthesized space photograph of territory of mountainous part of Cis-Baykal area taken from the "Soyuz-22."

Fig. 45. Color synthesized space photograph of territory of Cis-Baykal depression taken from the "Soyuz-22": A) fall-plowed fields; B) fields with grasses and agricultural crops; C) stubble

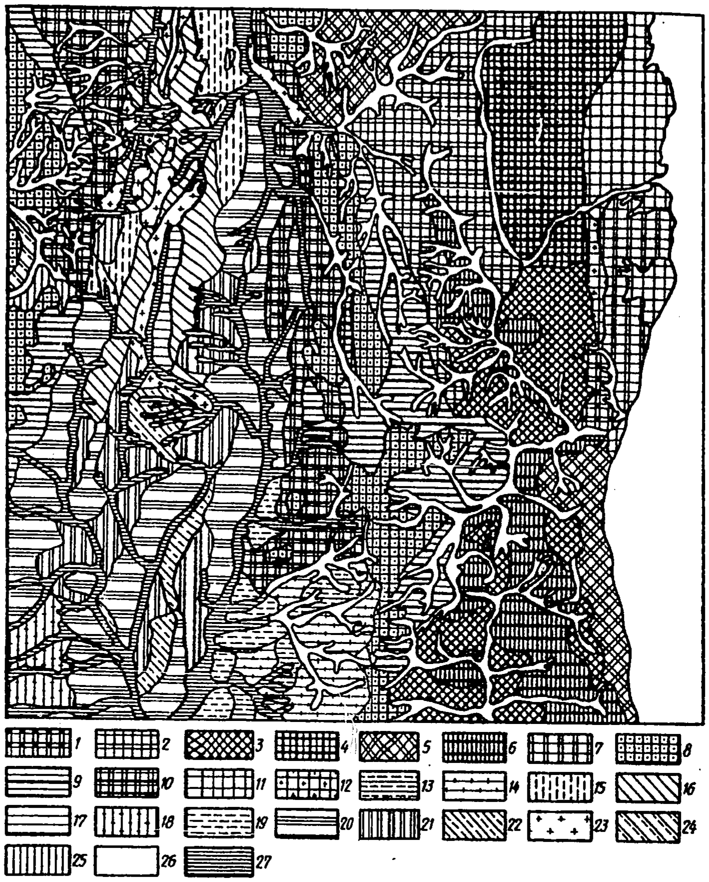

Fig. 46. Interpretation of soil cover of territories of the mountainous part of Cis-Baykalia and Predbaykal'skaya (Cis-Baykal) depression from color synthesized space photograph taken from the "Soyuz-22." (Key on next page)

of small spots of round and bladelike configuration of a light and light yellow color which impart a variolate-spotty pattern to the image of watersheds. Here, on flat poorly drained watersheds, a moist larch taiga with a ledum cover is formed. The soil cover is represented by straw-colored taiga solodized permafrost clayey loam and heavy clayey loam soils on watersheds: taiga degraded solonetz soils, meadow and meadow-swampy permafrost soils in thermokarst depressions -- so-called alasy (Fig. 43, see insert).

KEY TO FIG. 46

Soils: 1) mountain highly podzolic cold (including permafrost) soils; 2) mountain highly podzolic cold, including permafrost and mountain soddy-moderately podzolic cold soils; 3) mountain soddy-moderately podzolic cold soils; 4) mountain soddy-slightly podzolic cold soils; 5) mountain soddy-highly podzolic residual-calcareous cold and mountain soddy-moderately podzolic residual-calcareous; 6) mountain soddy-taiga cold, including permafrost soils; 7) mountain soddy-taiga cold, including permafrost and mountain soddy-forest cold soils; 8) mountain soddy-calcareous podzolized cold soils; 9) mountain soddy-calcareous, podzolized cold and mountain soddy-calcareous leached cold soils; 10) mountain soddy-calcareous leached cold and mountain soddy-calcareous leached eroded cold soils; 11) mountain chestnut cold soils; 12) mountain chestnut cold and mountain soddy-forested cold soils; 13) soddy-podzolic cold soils; 14) soddy-forest cold soils; 15) soddy-calcareous typical cold soils; 16) soddy-calcareous leached cold soils; 17) soddy-calcareous leached highly eroded cold soils; 18) gray forest cold soils; 19) leached chernozems with medium humus content, medium-thick, cold; 20) ordinary chernozems, medium humus content, thin cold; 21) ordinary chernozems, eroded cold; 22) highly eroded cold chernozems; 23) meadow-chernozem cold and meadow soils seasonally frozen for a long period; 24) meadow soils seasonally frozen for a long period; 25) swampy permafrost; 26) alluvial cold and meadow-swampy permafrost soils; 27) alluvial soddy cold soils, meadow soils seasonally frozen for a long time; 27) alluvial soddy cold soils, meadow soils seasonally frozen for a long time and swampy permafrost soils.

On the photograph from the meander-ox-bow lake image pattern it is easy to interpret the modern floodplain of the Vilyuy River with alluvial-meadow and meadow-swampy permafrost soils of different mechanical composition. Sandy shoals on the floodplain along the channel show up in a white color. The Vilyuy River has well-developed terraces which can be traced on the photograph from a greenish-cinnamon color and the spotty image pattern. Thermokarst processes are widely developed on terraces. There are many lakes and swales with meadow-swampy permafrost and taiga degraded soils in their central part and chernozem-meadow solonetz-like and solonchak-like soils along their periphery. On the photograph the swales are of a light yellow color.

The fourth natural region, which is clearly discriminated from the photograph photoimage, is situated along the right bank of the Vilyuy River. On the photograph it is interpreted from the nonuniform greenish-cinnamon-brown color. Here straw-colored taiga permafrost soils with a light clayey loam and sandy loam composition are formed under a pine and pine-larch taiga on soils of light mechanical composition with the participation of sands, as are soddy-meadow permafrost and soddy-forest permafrost soils with the participation of eroded soils.

An analysis of space photographs taken with the MKF-6 camera with respect to interpretability of the soil cover demonstrated the great detail of the soil image, the possibility of carrying out a soil-geographic regionalization of the territory.

Still another of the synthesized space photographs covers the region to the west of Lake Baykal. The photograph clearly shows the shore part, adjacent to the lake and occupied by the Primorskiy Range, which is covered by a pine-larch taiga. In this mountainous territory, from the different image color there is reliable discrimination of mountain soddy-podzolic cold soils and mountain soddy-calcareous and mountain chestnut cold soils, and in narrow mountain valleys clearly expressed on the photograph -- meadow-swampy permafrost soils (Fig. 44, see insert).

The Predbaykal'skaya depression extends from north to south to the west of the Primorskiy Range. Its surface with plateaulike watershed with an elevation of 800-1,000 m is highly dissected by river valleys with the presence of eroded lands. These are sectors of the Siberian wooded steppe with gray forest soils and cold chernozems in the southern part of the basin and soddy-calcareous soils in the northern part. The lands in this territory are intensively used in agriculture. They are reliably determined from the square-rectangular form of the image of fields. A different color corresponds to a different agricultural use of the fields. At the time of the survey -- the second half of September -- a black color corresponds to fields plowed in the autumn; a red color corresponds to fields with grasses; a lilac-gray color corresponds to sectors of fields occupied by the stubble of grain crops, etc. (Fig. 45, see insert). The areas of autumn-plowed lands were determined from the photograph without any error.

The results of interpretation of a synthesized photograph were finalized in the form of a soil map (Fig. 46). In the future a regular multizonal space survey of agricultural lands during the course of the growing season will make possible the reliable monitoring of changes in soil moisture content, the state of soils and agricultural crops; it will also make possible the timely discovery of areas having agricultural crops with diseases and prediction of their crop yield.

Thus, additional possibilities for the interpretation of soils are being afforded when using synthesized photographs on which by means of color it is easier to discriminate soils and their characteristics, such as erodability, swampiness, sandy mechanical composition, etc., and also to determine the different condition of fields and types of agricultural crops.

Soil Interpretation from Multispectral Space Photographs from "Meteor" Experimental Satellites

During recent years regular information on the state of the surface soil cover in our country has been received from the "Meteor" experimental satellites, which carry TV scanning apparatus with a low or medium resolution. In contrast to all space materials considered earlier this information is characterized by routineness, since for an analysis of the soil cover the photographs are sent to the appropriate agencies on the average one or two weeks after the survey and more frequently. A space survey is made from an altitude of 600-650 km in four spectral zones: 0.5-0.6; 0.6-0.7; 0.7-0.8 and 0.8-1.1 μm. The scale of the photographs is small (1:10,000,000); without a decrease in quality they can be enlarged to a scale of 1:2,500,000. The results of our investigations of the interpretability of the soil cover from these photographs for different survey seasons, having a medium resolution, indicated the following (Fig. 47A).

On photographs for the winter survey period (December 1977) it is easy to trace (especially in the zone 0.8-1.1 μm) the distribution of the snow cover over the soil surface. On a space photograph on the image of the territory of the East European Plain the entire steppe zone to the south of 55°N to the line Saratov-Rostov-na-Don has a uniform snow cover (light tone). Against this background in the northern part of the wooded steppe zone from the infrequent wedge-shaped areas of an almost black tone it is easy to interpret sectors of forest. Against the light image background of the snow cover there is reliable determination of the principal hydrographic network of the analyzed territory.

South of the line Saratov-Rostov-na-Don the image of the earth's surface has a mottled character, indicating a nonuniformity of the distribution of the snow cover. Sectors of Don sands show up very boldly in a dark gray, almost black tone. A dark gray photoimage tone is also characteristic of the virtually snow-free sectors of the Nogayskiye steppes, the black lands of the Kalmykia, land areas situated along the right bank of the Volga. On the other hand, the regions of the Stavropol'skaya Highland, Yergeney, the Caucasus foothills and mountains are well covered with snow.

On a winter photograph it is easy to trace the boundary between the forest zone with coniferous species (dark gray tone) and the steppe (light tone) zone.

On space photographs for a spring survey period (late March - early May 1978) we for the first time reliably interpreted the boundary of the chernozem zone -- typical and leached chernozems (dark, almost black tone of a dendritic pattern) from gray forest soils with the participation of soddy-podzolic soils (gray-light gray tone) from the different tone and pattern of the photoimage for the territory of the European USSR. The wedgelike nature of this boundary is clearly determined. For example, one of the extensive regions of southward propagation of the zone of gray

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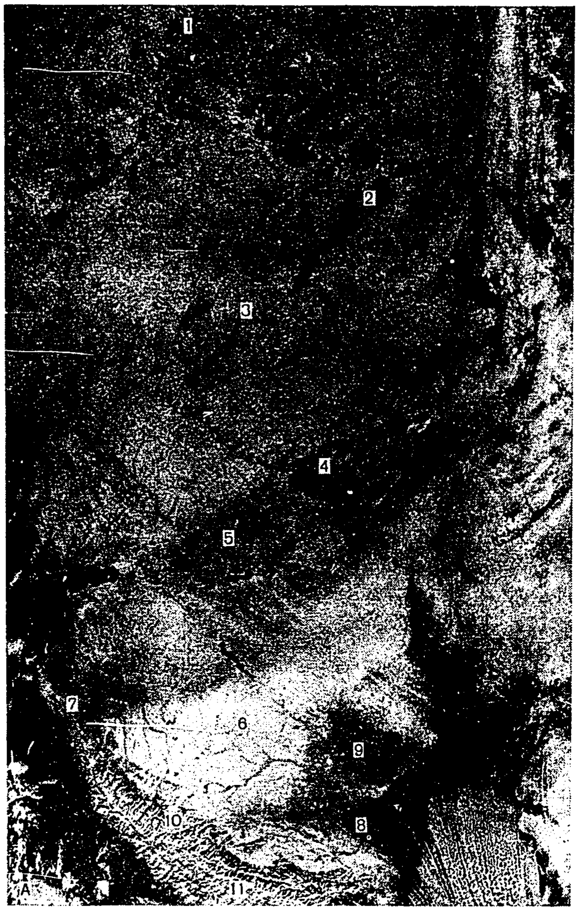
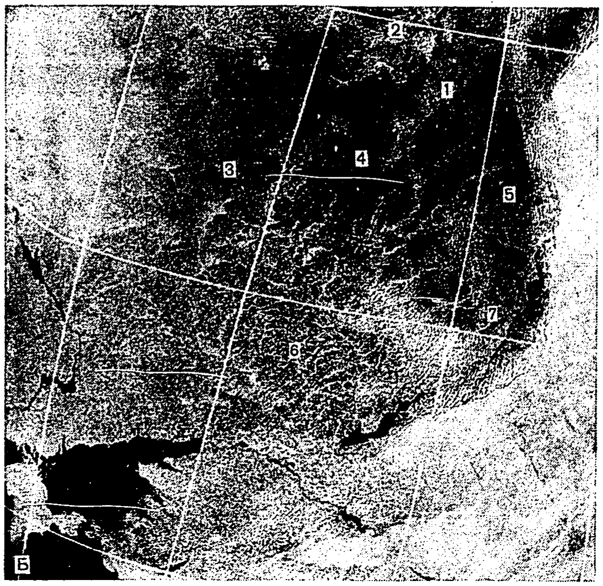


Fig. 47. Space photographs from "Meteor" experimental satellites showing territory of the European USSR. Scale 1:10,000,000, zone 0.8-1.1μm. Survey time: A) 12 December 1977; B) 7 May 1978. A, 1) mixed hardwood-coniferous forests on soddy-podzolic soils; 2) pine-southern taiga forests on soddy-podzolic sandy and swampy soils; 3) snow cover on Central Russian Highland and Oka-Don Plain; 4) Donskiye sands; 5) mottled snow cover in neighborhood of the Tsimlyanskoye Reservoir; 6) even snow cover on the territory of Yergeney and the Stavropol'skaya Highland; 7) lower reaches of the Kuban River; 8) delta of the Terek River; 9) Nogayskaya Steppe; 10) mountain-forest zone of the Caucasus with brown forest soils; 11) high mountain zone of the Caucasus. B, 1) soddy-podzolic sandy soils with participation of gray forest soils; 2) gray forest soils; 3) typical and leached chernozems of the Central Russian Highland; 4) typical rich chernozems, leached chernozems and meadow-chernozem soils of the Oka-Don Plain;



5) typical and ordinary chernozems of highlands along Volga; 6) ordinary chernozems and southern chernozems; 7) southern chernozems and dark chestnut soils.

forest soils is interpreted along the right bank of the Sura River to the latitude of Penza, taking in the northern part of the highland along the Volga. The next penetration of northern forest soils into the chernozem zone is well expressed on the photograph in the neighborhood of Saransk along the interfluve of the Moksha and Insar Rivers. The deepest propagation of gray and predominately soddy-podzolic sandy soils to the south to the latitude of Tambov is interpreted from a narrow (up to 25-50 km) zone of a wedgelike form along the right bank of the Tsna River. In Ryazanskaya Oblast a photograph clearly shows that gray forest soils in individual wedges enter into the chernozem zone along the right bank of the Para and the Ranova (right-hand tributaries of the Oka) (Fig. 47,B).

On space photographs in the IR zone taken in the spring survey period for the first time it was possible to discriminate intraprovincial regional differences in typical and leached chernozems with moderate humus content in the Central Russian Highland (gray photoimage tone of a dendritic pattern) from typical rich chernozems with a widespread occurrence of meadow-chernozem soils of the Oka-Don Lowland (dark gray, almost black tone). To the east of these, on the basis of the gray tone of the complexly dendritic pattern, it is possible to discriminate typical and ordinary chernozems along the highlands along the Volga.

To the south of the region of occurrence of typical chernozems and meadow-chernozem soils of the Oka-Don Lowland it was possible to determine (from the gray and light gray tone and the complexly dendritic image pattern of steppe rivers, numerous gullies and ravines) the boundary of occurrence of ordinary and southern chernozems. On spring photographs in the ranges 0.5-0.6μm and 0.6-0.7μm these differences to all intents and purposes cannot be interpreted.

On summer photographs in the IR survey zone it is impossible to trace these differences in the soil cover. On photographs from the summer survey period in the visible range (0.5-0.6 and especially 0.6-0.7μm) it is possible to interpret differentiation of the forest zone and the boundary between the forest and the steppe zones.

Another sector which we investigated from the photoimage of small-scale space photographs taken in the spring survey period covered the southern regions of the steppe and semidesert zones of the European USSR -- the Caspian area and the Syrtovoye Zavol'zhye region. On the space photograph brown semidesert soils with a high participation of solonetz soils, solonchak soils and sands, occupying the southern part of the Caspian Lowland, showed up in a light tone. On the photographs an almost white tone was characteristic of the area of the Ryn sands and the Prikaspiyskiye Karakumy. Against this light background of the image of brown semidesert soils it was easy to interpret alluvial-delta meadow and moist meadow soils of the Ural and Volga Rivers from a delta pattern of a gray tone. On photographs from the end of March to the beginning of May the image of these soils changes (due to a decrease in soil moisture content) from dark gray to light gray and locally begins to be similar to the surrounding areas.

In the territory of the Volga-Ural interfluve of the Caspian area north and west of the region of occurrence of the Urdinskiye and Central areas of the Ryn sands the tone of the photograph becomes light gray and gray with small black spots for the image of lakes and numerous solonchaks -- salinas (especially in the region of inundations of rivers of internal drainage -- Kamysh-Samarskaya depression and Chizhinsko-Dyurinsko-Balyktinskaya depression). A black image tone in spring is also characteristic of such large salt lakes as El'ton and Baskunchak, as well as Khaki salina, Lakes Aral-Sor, Inder and others. With respect to soils the area of inundation of rivers with internal drainage is represented by meadow-chestnut soils. Along the margins of estuaries there is extensive development of meadow and meadow-steppe complexes consisting of meadow soils, meadow solonchaks, meadow and meadow-steppe solonetz soils.

On the photograph to the north of the zone of occurrence of brown semidesert and light chestnut soils, having a light-light gray image tone, for the first time there was reliable determination of a zone of occurrence of chestnut and southern chernozems of the Syrtovoye Zavolzh'ye on the basis of the almost black tone of the fine dendritic pattern. These sharp differences in the photoimage of the analyzed zonal soils on the spring photographs are related to the difference (approximately by a factor of 2) in the humus content in the surface soil horizons and the better winter-spring moistening of the territory of the Syrtovoye Zavolzh'ye.

On summer photographs (survey of 13 August 1978, in the morning hours, scale 1:10,000,000, altitude more than 600 km) for the desert zone of the territory of Central Asia a good effect of soil cover interpretation was obtained in the red zone (0.6-0.7μm) of the spectrum. In the course of a comparative analysis of the soil photoimage, which we made using photographs taken in different spectral zones and existing small-scale soil maps, for the first time it was possible to make a clear interpretation of meadow and swampy saline and nonsaline and also old irrigated meadow floodplain soils of the Amudar'ya, Syrdar'ya and Zaravshan deltas. Several delta broadenings could be seen along the channels of these rivers. A different nature of the photoimage (lighter tone) is observed for the deltas of the Tedzhen and Murgab Rivers with desert takyrlike and irrigated desert takyrlike soils.

Southeast and east of the Central Karakum, on the basis of the different tone and pattern of the photoimage, it was possible to separate areas of sands on Paleogene and more ancient deposits from sands on Pliocene ancient alluvial deposits and gray soils of the foothill zone. In the mountains it was possible to determine mountain cinnamon soils. These characteristics of the photoimage of the soil cover were traced less well from photographs in the IR and especially in the green spectral zone.

The use of small-scale multizonal routine space information from the "Meteor" experimental satellites indicated that using photographs (especially in the zone 0.8-1.1μm for the winter and spring survey periods) it is possible to observe the distribution of the snow cover over the earth's surface and the change in soil moistening and to interpret zonal, subzonal and regional soil differences.

Chapter 8

INFRARED AND RADAR METHODS FOR INVESTIGATING SOILS

At the present time the methods for obtaining photoelectronic images of soils and agricultural crops by the nonphotographic approach are in the stage of experimental development. These images and traces are a valuable supplement to photographic methods because they make it possible to obtain information on the energy radiated by the features on the earth's surface to be analyzed in contrast to photographs, which pick up reflected solar energy.

Direct photographic systems are characterized by a high resolution, good geometrical image quality, ease in visual perception and simplicity of photoprocessing. However, these methods to a considerable degree are dependent on weather conditions and their use is restricted to a narrow part of the electromagnetic spectrum (visible and near-IR -- to 1.1μm).

Indirect photoelectronic systems take in the entire range of the electromagnetic spectrum. They can be classified as passive, among which IR radiometers are in the widest use, and active -- radars and lidars operating in zones from the ultraviolet to the near-IR.

In order to identify types of agricultural crops and to ascertain their crop yield it is necessary to use both nonphotographic sensors and the full range of available photographic materials.

During 1971-1976 specialists in our country made a study of natural resources and especially geological formations using a Fotoskaner-4 instrument. It registers radiation in three channels: 0.3-0.4; 0.5-0.7 and 0.8-1.1μm. It was found that scanner UV and IR photographs contain more information than black-and-white and spectrozonal photographs. On UV photographs it was possible to see semiconcentric forms which did not show up on photographs obtained in other zones (Apostolov, Selivanov, 1974).

In this section we will examine the possibilities of nonphotographic photoelectronic methods using sensors responsive to the IR and microwave spectral ranges and data from a radar survey. The development of these remote methods will make it possible to determine soils, their properties and composition, types of agricultural crops, level and status of their development and predict yields from an aircraft or from space.

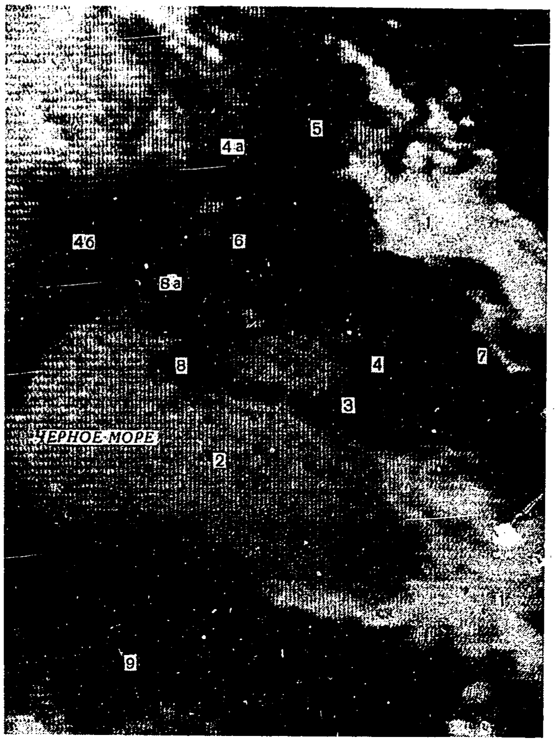


Fig. 48. Interpretation of IR image of territory of southern European USSR (spectral range 8-12μm); survey in July 1972 at 1400 hours from "Meteor": 1) clouds; 2) waters of Black Sea and Sea of Azov; 3) alluvial soils of Danube and Kuban Rivers; 4) micellar-calcareous chernozems of plains around Sea of Azov; 4a, 4b) ordinary and typical chernozems of cis-Dnepr lowland and marginal parts of the lowland adjacent to the Black Sea; 5) typical and leached chernozems of the Central Russian Highland; 6) ordinary chernozems of highlands along the Dnepr; 7) southern chernozems and dark chestnut soils of the Sal'sko-Manychskaya ridge; 8-8a) southern chernozems and dark chesnut soils of the steppe Crimea and highland along the Black Sea; 9) chestnut and light brown soils of semideserts of the Anatolian highland of Turkey.

Infrared Soil Survey

This photoelectronic survey of the earth picks up the thermal radiation of the surface of different soils and agricultural crops. Investigations of the IR spectral zone (1.2-2000μm) indicated that there are two clearly expressed "windows of transparency" of IR atmospheric radiation; the first takes in the range from 1.8 to 5.3μm; the second, with which the maximum of spectral radiation of features on the earth's surface is associated, is from 7 to 14μm; in the remaining part of the IR range, other than the "window of transmission" (transparency), IR radiation is rather strongly absorbed by water vapor, carbon dioxide, ozone and other impurities present in the atmosphere.

An IR survey (IR imagery) is made using special high-response photoelectronic detectors having an optical-mechanical scanning device. In the receiver-detector the thermal radiation is transformed into light signals which from the screen of a cathode-ray tube are registered on light-sensitive materials in the form of curves or photographs.

On a photograph the range of gray tones reflects the relative temperature of individual sectors of the soil cover surface. With a high response of the radiometer detectors these instruments are capable of registering insignificant temperature differences.

Several types of single-channel radiometers are being produced in the United States; these have interchangeable blocks of sensing elements (detectors). Multichannel radiometers have been created which register both emitted and reflected energy in the range 0.36-2.0μm. There are radiometers with 24 channels. The ray of reflected energy in the course of optical-mechanical scanning is incident on an optical prism, by means of which it is broken down into individual ranges, each of which has its own detector. When there are corresponding detectors on the earth, transmitting temperature from control sectors of the earth's surface to a special radiometer mounted on an aircraft, it is possible to compute the zero reference line, carry out calibration of the thermograms and make an office determination of up to 25 layered images reflecting temperature and compile terrain heat maps.

Investigations in the IR zone, in the wavelength range 3.69-5.5μm, were carried out in Michigan (during the nighttime and daytime) and in California (during the daytime) in an irrigated region. The collected materials made it possible to determine water supplies and the degree of soil irrigation. On the basis of IR images it is possible to obtain valuable information on the drainage of the territory and the presence of sectors with excess moistening. The best results in the study of swampy lands was obtained from IR data -- in the range 8.5-12.5μm.

The IR images obtained from space using the "TIROS" satellite at wavelengths 8-13μm made it possible to distinguish surfaces with different temperature. The IR materials obtained using the United States "Nimbus-1" and "Nimbus-2" meteorological satellites in the range 3.4-4.2μm make it easy to interpret volcanic regions, hot springs and other features (Merifield, Gronin, et al., 1969). The ranges 3-5.5 and 8-14μm are promising for the purposes of an IR survey of the earth's surface. However, the most contrasting image of terrestrial features is obtained in a survey in the range 8-14μm.

With an increase in moisture content the soil temperature decreases and therefore on the IR photographs on the basis of thermal contrasts it is possible to detect sectors with increased moisture content. Experience has been gained in detecting zones of increased moisture content of sands in the Karakum desert on the basis of data from a nighttime IR survey in the range 3.5-4.8μm from the "Nimbus" satellite. An ancient channel of the Niger River was discovered in Africa on the basis of a thermal anomaly caused by different moisture content.

In our investigations we used IR images obtained from a satellite of the "Meteor" system in the range 8-12μm. With a satellite flight altitude of 600-650 km an IR scanning radiometer registers radiation along the flight trajectory of a satellite in a zone with a width of 1,100 km. On IR images anomalies with a light tone correspond to territories with a low soil surface temperature; a dark tone corresponds to sectors with a higher temperature. An analysis of the photographs indicates that in the case of cloudless weather or weather with few clouds it is possible to interpret thermal nonuniformities of the cloud cover.

Interesting information was obtained from an IR image from the "Meteor" satellite showing the territory of the southern European USSR. The survey was made in July 1972 at 1400 hours (Fig. 48). Clouds -- the coldest anomalies -- appeared in white and almost white tones. Moderately cold anomalies (light gray tone) correspond to the water surfaces of the Black Sea and the Sea of Azov. Somewhat warmer (gray tone) anomalies correspond to damp sectors of alluvial-meadow and meadow-swampy delta soils of the Danube and lower reaches of the Kuban. The next thermal gradation (darkish-gray tone) is characteristic for the plain surrounding the Sea of Azov with micellar-calcareous chernozems, the lowland along the Dnepr with ordinary and typical chernozems and the marginal parts of the lowland near the Black Sea with transition to the Volyno-Podol'skoye Plateau with ordinary chernozems.

Still another level (dark gray tone), clearly interpreted on the photograph, corresponds to the image of the western slopes of the Central Russian Highland with typical leached chernozems. The next thermal level (dark tone) corresponds to the image of the soil cover of the highland along the Dnepr with ordinary chernozems. A gray-black tone was characteristic of sectors of the Sal'sko-Manychskaya Ridge with southern chernozems and dark chestnut soils. The Kuma-Manychskaya depression appeared somewhat colder.

The next very warm anomalies are characteristic for the territory of the steppe Crimea and the lowland along the Black Sea (almost black tone) with southern chernozems and dark chestnut soils. The territory of mountainous Crimea appeared considerably colder; with respect to its thermal indices it is similar to sectors of the lower reaches of the Kuban.

Thus, in the investigated territory in an afternoon period of the space survey it was established for the first time that sectors of the Central Russian Highland and the highland along the Dnepr and the Sal'sko-Manychskaya Ridge were warmer than the adjacent regions of the plains near the Dnepr and the Sea of Azov. The mountainous territories of the Crimea and the Caucasus appeared the coldest, as did the swampy lower reaches and the deltas of the Danube and the Kuban. On the other hand, the warmest sectors were the steppe regions of the Crimea, the lowland near the Black Sea and the semidesert regions of Turkey. In the territory of the lowland near the Black Sea, on the basis of the coldest thermal anomaly, it was easy to detect the region of the Kakhovskoye Reservoir.

With respect to resolution IR space images are inferior to photographs and therefore for a definite survey time they can be used as interesting additional information for use with space photographs. However, IR images can be of great independent interest for study of the dynamics of thermal anomalies from nighttime, daytime photographs and those taken at different times and in different seasons.

Radiothermal Soil Survey

A radiothermal survey, or passive radar, registers the natural radiothermal emission of the soil cover in long-wave thermal rays (0.3-30 cm). The photoelectronic apparatus for the reception of these rays is supplied with a special antenna. The total radiothermal radiation is determined using the formula $E \approx \varepsilon T$. In the case of an IR survey the emissivity coefficient (ε) changes little with a change in wavelength; in the radiothermal range it is subject to considerable variations. With an increase in wavelength (λ) there is a decrease in the ε value. For example, for water with $\lambda =$ 1 mm $\varepsilon = 0.3$; with $\lambda = 100$ cm $\varepsilon = 0.05$. For the millimeter and especially the centimeter range there is a virtually complete transparency of the atmosphere and cloud cover and therefore this method is promising for a radiothermal survey from space.

The "Nimbus-5" satellite carried a microwave radiometer which made it possible to determine the moisture content in the soil layer at a depth of several centimeters, but with an approximate spatial resolution of 25 km (Idso, Schmugge, et al., 1975).

In contrast to the infrathermal range, in the radiothermal spectral zone there are small diurnal variations of radiothermal contrasts. On the other hand, there is a considerable change in radiothermal contrasts in dependence on moisture content, salinity, structure and composition of the soils (Shilin, 1971). The use of passive microwave technology made it possible to determine the composition of the soils and ground, as well as moisture content, and also to detect the presence of voids in the immediate neighborhood of the surface (Ulaby, Cihlar, Moore, 1975). Using SHF methods for deep sounding, it is possible to expect the collection of data on soils to tens of meters in depth.

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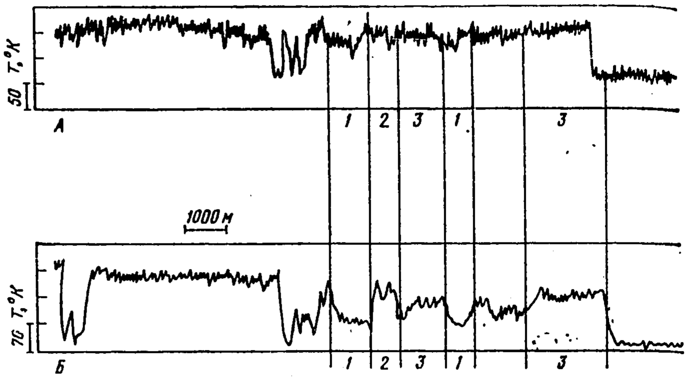

Fig. 49. Image of radiothermal signals during flight over moistened soil surface (Krymskaya Oblast) (from A. Ye. Vasharinov, et al., 1974): A) wavelength 0.8 cm, $\theta = 20°$ horizontal polarization; B) wavelength 3.4 cm, $\theta = 60°$ horizontal polarization. 1) soil surface; 2) corn field; 3) field with vegetation of different height).

In an aerial survey of irrigated fields in Arizona (United States) the moisture content of soils was studied using microwave radiometers operating in the wavelength range 0.8-21 cm. For control purposes in 200 sectors with different irrigation times a field method was employed for determining soil moisture content at a depth of 0-15 cm. The results indicated that when using a wavelength of 1.55 cm there was no dependence of the reflected signal on soil moisture content (10-15%) or it is slight. If the moisture content is greater than this level, there is a linear dependence between the value of the reflected signal and soil moisture content. In the case of use of a microwave radiometer with a wavelength of 21 cm for a soil moisture content from 0 to 35% the reflection is a linear function of moisture content (Schmugge, et al., 1974).

In the USSR interesting investigations for measuring the moisture content of the earth's surface from space and using aerial vehicles are being carried out using SHF radiometric apparatus. In 1973 Basharinov, et al. (1974), in a survey from an aircraft using SHF apparatus, studied the radiation characteristics of soils for unirrigated lands in the middle (Kurskaya Oblast) and southern (Krymskaya Oblast) zones of the European USSR.

Soil moisture content and the influence of vegetation on the radiobrightness characteristics of moist soils were studied using radiometers having a response of about 0.5° and operating in the ranges 0.8 cm and 3.4 cm. The axes of antennas with angular resolutions 1 and 3° were oriented at angles 20 and 60° to the horizon. Resolution on the ground was from 1 m to 10 m because the flights were made at heights from 50 m to hundreds of meters over the surface of the experimental sectors.

Figure 49, for the territory of Krymskaya Oblast, shows the results of measurements made after a rain. They show the influence of the vegetation cover on the radiation characteristics of the moistened surface. The differences are most clearly visible when using a radiometer operating in the range 3.4 cm.

In our investigations in the territory of the experimental sector of the steppe zone during the field period we made determinations of soil moisture content by the thermoweight method along the aircraft flight path in fields with different moisture content. Differences in surface moisture content of the fields in the layers 0-5 and 0-10 cm were as follows (measurements made 8 or 9 times): fields in sugarbeets -- 23.2 and 23.8%; fields in fallow, dessicated from the surface -- 10.3 and 15.3%; fields in fallow after passage of a drill -- 19.3 and 21.5%. A comparison of these data with traces obtained as a result of not less than 5 aircraft flights over the mentioned fields indicated that all these results of field moisture content were registered in changes of the instrument curve.

Everything stated above makes it possible to consider this method to be promising for study of the soil cover, especially for determining the surface moisture content of soils.

Radar Survey of the Soil Cover

The use of radar systems is among the new photoelectronic methods for obtaining information on soils and agricultural fields. The beginning of use of side-view radar systems, giving an image, dates back to 1950. This method substantially supplements other systems giving an image of the soil cover.

Using a high-resolution radar, specialists in the United States carried out a survey of the Amazon and Orinoco basin, a territory in the moist equatorial zone usually shrouded by cloud cover. The survey was made at a scale of 1:400,000 with a resolution of about 20 m on the ground. In 1970 the RADAM project was carried out for investigating soils, vegetation, relief and mineral resources by means of a radar survey. Radar photographs are being used successfully for study of the moisture content of soils and river systems and in agriculture. They are being employed in investigating the distribution of natural vegetation and sown crops, in predicting yields and in planning agronomic measures (Simonett, 1968). In the next 10 years radar surveys of the environment should become one of the principal methods for studying dynamic phenomena and processes.

The most valuable property of this new type of survey of the soil cover is that a radar apparatus can operate in the absence of visibility -- through fog and clouds and also at nighttime (Komarov, et al., 1973). This is especially important in the study of the soil cover of the northern inaccessible regions of our country. In comparison with materials from an aerial photographic survey, the scale of radar images is small: from 1:60,000 to 1:400,000. It is not determined by the aircraft flight altitude but by the parameters of the equipment used. In a radar survey of the soil cover the sources of radiation of waves in the centimeter range and the detector are situated aboard the aircraft. The signal reflected from the earth's surface, in the limits of the azimuthal angle within which the irradiation occurs, is picked up by an antenna and after transformation of the radar signals in the transmitter-receiver is registered on a cathode-ray tube in the form of one scanning line. The intensity of the reflected signal, determining the brightness of the luminous spot, is dependent on the surface roughness, nature of the relief in the analyzed territory, the physical properties of the soil cover, soil moisture content and the employed wavelength. By means of a photoregistry unit the line image on the cathode-ray tube and the intensity of the reflected signal are photographed on a film whose rate of movement is proportional to the speed of aircraft movement.

As a result, signals reflected from the earth's surface show up on a photographic film with different intensity. The radar photoimage of the ground surface is similar to the aerial photographic image and in its interpretation it is possible to apply the experience of interpretation of aerial photographs. The radar images give the detailed structure of local relief, a change of which is closely linked to formation of the soil cover, its structure and complexity. Using radar images it is easy to interpret soils which are moistened to different degrees; data from a radar survey can be used in identifying crops.

An analysis of radar photographs at a scale of 1:90,000, obtained using the "Toros" side-view radar system (survey territory -- northern Balkhash region (Severnoye Pribalkhash'ye), indicated that at the tops of ridges and spurs a light gray tone corresponds to thin, poorly developed gravelly brown desert-steppe soils formed on the eluvium of granites and quartz-porphyrites. A gray tone corresponds to brown desert-steppe poorly developed soils formed on the fine-grained eluvium of sandstones. On proluvial deposits, from the dark gray image tone and the dendritic form of the soil contours there is reliable interpretation of meadow-brown and meadow-chestnut soils. Frequently they are solonchak-like. The photoimage of alluvial-meadow soils of the low terraces of major valleys is characterized by a banded pattern of gray and light gray tone in dependence on the degree of expression of the meadow process. A light sinuous narrow band is the image of an intermittent watercourse.

Using radar photographs of the territory of the semideserts of the northern Balkhash area it is possible to make a reliable interpretation of different types of Quaternary deposits, separate soils on the basis of moistening regime into automorphous, polyhydromorphous and hydromorphous, and also use these materials for soils regionalization (Semenova, Mozhayeva, 1973).

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In our investigations we used radar photographs of the territory of an experimental sector of the dry steppe zone at a small scale taken from an altitude of 4,500 m using the "Toros" system. The survey was made at nighttime in late July 1975 in the presence of stratocumulus clouds. An analysis of the radar photographs indicated that they can be used in reliable interpretation of the soil-geomorphological characteristics of the principal natural regions of this territory.

For example, the photoimage of an undulating sandy plain is characterized by the presence of a great many lakes of a dark gray, almost black tone with a rim of solonchaks of an almost white tone. The image of dark chestnut sandy and sandy loam soils has a moiré pattern. Virginland vegetation shows up in a dark gray tone. An antierosional contour farming system occurs here widely. In the fields strips of an almost black tone correspond to stands of grasses (for the most part crested wheatgrass); strips with a light gray tone correspond to plantings of corn or sunflower. The image of the contour farming system is interpreted more clearly and with greater contrast from radar photographs than from materials from a multizonal survey.

The next soil-geographic region, occupying the territory of an ancient runoff trough with a complex soil cover, shows up on the radar photographs with a lesser contrast than on multizonal materials. Plantings of crested wheatgrass and virginland sectors show up in a dark gray tone on which sectors with solonetz soils show up as spots of a light gray tone.

On these photographs of plateaus with dark chestnut calcareous and meadow-chestnut soils in swales it is easy to see squares of fields (with an area of 400 hectares) of a light gray tone -- the image of spring wheat. Against this background small spots of an almost black tone correspond well to meadow-chestnut soils; a light image tone corresponds to sectors of excavated dark chestnut soils.

Amidst the squares of fields of a light gray tone, from the dark gray, almost black image tone it is easy to interpret infrequent fields of bare fallow. Fields with plantings of corn and sunflowers are reliably differentiated from the fields of spring wheat on these photographs due to their bright-light image tone. Sectors with different sowing times were determined amidst plantings of agricultural crops due to the different image tone.

The eroded slope of plateaus toward the Turgayskaya depression was determined very clearly on radar photographs from the nonuniform spotty-dendritic pattern of a light gray (blurred sectors), gray or dark gray tone.

The effectiveness of a radar survey of the soil cover is increased sharply when it is carried out during a period when the vegetation is without leaves. The proper choice of the angle of inclination of the radar and its frequencies are also of great importance.

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In order to study the composition of soils by means of side-view radars the surface is irradiated with radio waves of a definite length. By increasing the wavelength or the radiated power it is possible to determine the nature of the upper soil horizons. We note that among the principal advantages of active radio techniques -- radar systems, in addition to a nondependence on weather conditions and time of day, we should include the possibilities of determining the properties of the surface and subsurface soil horizons, a nondependence of survey scale on altitude, and also the possibility of obtaining contrasting images of optically noncontrasting features (such as soils) and ensuring a considerably better resolution in comparison with SHF radiometers.

In conclusion we note that the effective study of the soil and agricultural resources of the earth is possible when such work is carried out by combined aerospace methods, including aerial photographic and photoelectronic. The development of these new methods will make possible a more effective inventory and use of land resources and an evaluation of the fertility of soils and the yield of agricultural crops. There will be more effective work on soil melioration, better protection of soils against erosion, it will be easier to detect diseases of agricultural crops in the early stages, etc.

Chapter 9

EFFECTIVENESS OF USE OF AEROSPACE METHODS IN STUDYING SOIL RESOURCES

Soil Mapping from Aerial and Space Photographs

At the present-day scientific and technical level of development of aerial and space surveying of the earth soil mapping is one of the principal directions in the use of aerospace methods in soil science and agriculture (where they give a substantial effect).

Today the progress of soil mapping, the process of study of the soil cover, correction and compilation of soil maps is inconceivable without the use of aerospace materials. A soil map is the principal scientific document characterizing the productive-economic qualities of the land and therefore it plays an important role in its rational use. In the study of the soil cover and in the compilation of soil maps, carried out in our country by a system of land use agencies and scientific research institutes, there must be an objective characterization of the natural characteristics of the territory to be mapped, a high accuracy and detail in the representation of the soil cover and its scientifically sound generalization. The use of aerospace methods is exerting a revolutionizing influence in the solution of these problems.

The refinement and acceleration of work in the compilation of soil maps are dependent to a considerable degree on the nature of the base used. It is entirely obvious that the higher the quality of the base used, the greater will be the detail of the natural conditions represented on it and the better will be the quality of the soil survey results. A geographic base rich in detail makes it possible for the soil scientist, relatively simply and rapidly, to determine the position and rather precisely to stipulate the sites for soil profiles and samples. A geographic base with a good representation of relief makes possible a considerably more precise siting of soil profiles in its individual elements and far more reliably define and draw the boundaries of soil units because the spatial changes of soils are dependent to a considerable degree on relief changes.

Investigations of recent years have shown (METODIKA SOSTAVLENIYA..., 1962; RUKOVODSTVO PO SOSTAVLENIYU POCHVENNYKH KART, 1964; KRUPNOMASSHTABNAYA KARTOGRAFIYA POCHV, 1971) that the best bases for the compilation and correction of large-scale soil maps are topographic maps or aerial photoplans with contours and aerial photographs. The earlier extensively used land use plans without the representation of relief are unsuitable for this purpose because soil maps compiled on such a base with respect to accuracy and quality do not meet modern requirements. In addition, the work input of the soil scientist is very great when using this type of base.

The fundamental theoretical principles in the field of interpretation and analysis of soil interpretation criteria were used in developing methods for the compilation of soil maps from aerial and space photographs.

Methods for the compilation of soil maps from aerial and space photographs (for territories in which soils have been poorly studied). The compilation of soil maps by aerospace methods is subdivided into three stages: preliminary office work, field work and final office work. When using aerial and space photographs, especially multizonal photographs, in this traditional process of investigating and mapping of the soil cover there is a marked increase in the volume of work on preliminary office procedures. In the first stage of the work a study is made of the literature and cartographic materials, including topographic maps of the investigated region. A topographic map, in accordance with the scale used, makes it possible to obtain data on the characteristics of relief in the territory to be analyzed. However, it does not make it possible to judge the nature of the soil cover over the territory of a farm, region or definite natural region to be mapped and affords no possibility, still under office conditions, for defining the limits and content of individual soil areas or units. In addition, for soil mapping the image of relief on topographic maps does not always fully reflect the microrelief in the territory. An aerospace survey makes possible the relatively rapid collection of materials with a high accuracy and objectivity. In comparison with topographic maps they are characterized by a greater detail of the image of the earth's surface and wealth of detail, a direct or indirect representation of the soil cover and the possibility of establishing its interrelationships with other landscape elements.

At the same time, when working with space photographs there is a sharp increase in the role of topographic and soil maps available for the investigated region. This is attributable to three factors:

First, whereas when using aerial photographs orientation and tie-in are readily accomplished in the field, when using space photographs this work is done initially from maps and it must be remembered that the detail of the space photographs is greater than the detail of the maps (of similar scales).

Second, the use of soil and topographic maps makes it possible to clarify the possibilities of interpretation of soils on space photographs, the degree of detail and generalization of the image of soils, relief, hydrographic elements, and also to establish interpretation criteria for a number of soils.

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Third, a topographic map (as in the case of aerial photographs) is used in conveying the results of interpretation of space photographs (frequently unrectified) and in compiling a soil map of the corresponding scale.

In the preliminary period work on the use of aerospace photographs for study of the soil cover begins with a general review from them, using a preliminary montage of photomosaics of the investigated territory. It is necessary that these be constantly compared with materials on available soil maps and topographic maps. In the course of this work from the photoimage of the photographs and the nature of the relief on the topographic maps it is possible to determine sectors with more or less uniform natural conditions and to accomplish orientation and tie-in of aerial and space photographs to elements of the geographic situation on the topographic maps. This can be done most reliably on the basis of an analysis of the hydrographic and gully-ravine network (especially in the case of use of space photographs).

In the case of large- and medium-scale surveys, from land use maps the administrative boundaries of farms or regions are transferred to topographic maps and photographs during the preliminary period and the photographs required for further work within their boundaries are kept. When using aerial photographs having a 60% end lap within the limits of each flight line they are divided into two sets (even and odd numbers). One of the sets is used in defining the work area; the other set of photographs is necessary for a stereoscopic interpretation of the soil cover.

The next important stage is carrying out a preliminary soil interpretation on the basis of aerial and space photographs. When using aerial photographs for the compilation of large-scale (1:10,000-1:25,000) and medium-scale (1:100,000-1:200,000) soil maps this stage involves the following.

By means of stereoscopic instruments (stereoscope, interpretoscope, etc.) and an analysis of interpretation criteria on photographs, within the limits of the work area it is possible to define the boundaries of soil areas. The basis for their interpretation includes tone and pattern (texture) of the photoimage, including the size, shape and shadows of features, the nature of relief and other criteria. A summary of the soil areas is placed at the boundaries of the work areas. All the soil areas on the basis of the degree of interpretability are classified as reliable, doubtful (shown by a dashed line) and those which cannot be determined under office conditions.

In the stereoscopic interpretation of space photographs taken from altitudes of 200 km or more it must be remembered that only large forms of relief with an amplitude of 100 m or more are perceived three-dimensionally.

In the office interpretation of doubtful soil units and those which cannot be determined visually the soil scientist is assisted considerably by the use of an image analyzer -- the "Kvantimet-720." The experiments which have been carried out have indicated that when it is used there is additional differentiation of uniform soil areas and an objective quantitative evaluation is obtained.

When the soil scientist has a knowledge of the soil cover of similar territories, when he has samples of the interpretation of soils from photographs, it is possible to make a preliminary diagnostic determination of the soil cover which is then partially checked in the field. If there are no interpretation samples for similar soils, the soil cover is unfamiliar to the soil scientist or he has no experience in the interpretation of soils, the diagnostic interpretation of the soil cover is carried out only under field conditions.

In this connection it is possible to distinguish three principal variants: a) use of aerial and space photographs for refining existing soil maps for territories where the soils have been well studied (see next section); b) use of aerospace methods for refining and recompiling soil maps for territories where the soils are poorly studied; c) use of aerospace methods in soil mapping of inaccessible territories where the soils have not been studied.

It was established when using multizonal photographs during the preliminary office period that the principal results in soil interpretation should be obtained from photographs in the blue-green, red and IR zones, containing the most soil information. Photographs in the IR and blue-green spectral zones under office conditions, together with photographs in the red zone, make possible a more reliable and objective interpretation of soils and the obtaining of new information for a number of soil units.

After carrying out a preliminary office interpretation of the soil cover the results of the areal and in part the diagnostic determination of soils are transferred by means of appropriate projection instruments (photorectifier, projector, Clara camera, etc.) onto a topographic base. The results of soil interpretation are transferred onto a photoplan (if it is used as a base) using the geographic situation and the photoimage, similar to photographs.

In this way a map of the preliminary interpretation of soils is compiled. On the basis of this map and available photographs it is possible to determine soil-geomorphological regions for which (when making a medium-scale soil survey) it is possible to prepare interpretation "keys" (area -- one or two aerial photographs), select the most rational routes and sites for obtaining the principal soil profiles and draw up a plan for a field soil investigation.

Field studies for soil mapping purposes with the use of aerial and space photographs begin with a general familiarization with the soils -- in the process of a reconnaissance of the investigated territory. During the initial period it is especially important, simultaneously with orientation, tie-in and description of the soil profiles, to clarify stable interpretation criteria for the soil cover.

In a large-scale soil survey it is customary to use the continuous surveying method; in medium- and small-scale mapping the reconnaissance-"key" survey method is employed. When "keys" are available work on soil mapping and field interpretation begins from these sectors. Their number is determined during the the preliminary office period and is dependent on the peculiarities of structure of the soil cover. In the case of a medium-scale survey of a soil-geomorphological region a soil interpretation "key" is prepared. In the case of "key sectors" the soil units and typical structures of the soil cover are supported by soil profiles. In the course of this work there is accumulation of experience on the field interpretation of soils, which makes it possible to proceed to the next stage in the work on the mapping of the soil cover by the reconnaissance method. The sites for the soil profiles are determined on the photographs on the basis of the photoimage tone and pattern.

The reconnaissance-"key" method is used when space photographs are employed. A knowledge of the interpretation criteria makes possible successful interpretation of the soil cover between reconnaissance lines, applying the principle of geographic analogues. In the case of a good interpretability of soils, especially when using a multizonal survey, the number of soil units discriminated from photographs is usually greater than when using only topographic maps. Accordingly, with retention of the norms established for a definite scale for the digging of the main and secondary pits a number of soil units will not be supplied with such test pits. When using photographs their conditionality will be backed up by a similar photoimage with sectors for which there are test pits, as a result of a survey in "key" areas and along reconnaissance lines and extrapolation of the results to territories between field lines for which no data are available.

For territories with a complex soil cover the number of main test pits may even be somewhat greater than set by the present-day norms. However, the number of test pits needed for clarifying the boundaries of soil units is reduced by several times. As a result, the use of photographs enables the soil scientist, working in the field, to carry out a higher-quality, fundamental study of the soil cover. The result of field work is a field compilation of a soil map with a legend and soil interpretation symbols.

In the post-field office period the materials from the soil survey and the results of the soil interpretation are formalized in final form. After the analytical processing of soil samples the legend and soil map are finally backed up with the writing of an explanatory text to the map. The results of soil interpretation are finalized in the form of interpretation samples for the soil cover. These are usually prepared for the sector of "key investigations."

Each of the soil interpretation samples consists of the principal photograph and two adjacent photographs (triplet) for a stereoscopic study of the soil cover. A sample of photo interpretation in the form of a fragment of the soil map with its legend is appended to them.

The next document is the explanatory text with a brief description of the natural conditions, soil cover and characteristics of its interpretation with a compilation of a table of soil interpretation indicators.

Interpretation samples, for the purpose of their subsequent use, are accompanied by an indication of the taxonomic unit, in accordance with the scheme for soil-geographic regionalization of the USSR, the time when the survey is made, the scale and the type of film. In the case of multizonal photographs there is an indication of the spectral zone used and photographs of other survey spectral zones are given.

Methodological procedures for the compilation of medium- and small-scale soil maps from space photographs (for agriculturally exploited lands). At the present time in the agriculturally exploited territories of our country more than 94% of the kolkhoz and sovkhoz lands are supplied with large-scale soil maps. Accordingly, it is necessary to generalize this rich material from soil mapping investigations of farms and compile medium- and small-scale soil maps for rayons, oblasts and individual republics in the country

On the basis of investigations made during recent years in the field of medium- and small-scale soil mapping with the use of space photographs and with the compilation of samples of soil maps for different natural regions of the steppe, dry steppe and desert zones, we will cite a number of methodological instructions on the use of space photographs.

1. Depending on the complexity of the soil cover and the area of land coverage, it is desirable that the generalization of data from a large-scale soil survey be carried out to scales 1:100,000, 1:300,000-1:500,000 and 1:1,000,000.

In the compilation of maps at a scale 1:100,000-1:200,000 it is possible to recommend aerial photographs at a scale of 1:30,000-1:100,000 and space photographs at a scale of 1:200,000, as well as original and enlarged photographs at a scale of 1:1,000,000.

In the compilation of maps at a scale of 1:300,000-1:500,000 it is necessary to use space photographs at a scale of 1:200,000, black-and-white and color spectrozonal photographs at a scale of 1:1,000,000, enlarged by a factor of 2-4, and also black-and-white multizonal photographs taken with the MKF-6 camera, and color photographs synthesized from them, enlarged by a factor of 4-5 in comparison with their initial (1:2,100,000) scale.

In the compilation of maps at a scale of 1:1,000,000 it is recommended that use be made of black-and-white and color spectrozonal space photographs at a scale of 1:1,000,000, enlarged by a factor of 2-3, and multizonal photographs, taken with a MKF-6 camera with enlargement by a factor of 3-5, as well as photographs at a scale of 1:200,000-1:300,000 with subsequent reduction. It is also possible to use space photographs at a scale of 1:2,500,000 taken from the "Salyut" orbital station and enlarged 2^x-5^x. These same space materials can be used in the compilation of sheets of a soil map at a scale of 1:2,500,000.

Experience has shown that in the compilation of medium- and small-scale soil maps it is desirable to use photographs of this same scale or twice as large.

2. Work on the compilation of generalized soil maps at medium and small scales with the use of space information can be divided into three stages: preliminary office, field and final office work.

3. The use in the office period of a complex of stereoscopic, optical-electronic apparatus for an analysis of photoimages, optical-mechanical projectors, photorectifiers and synthesizers for the synthesis and transfer of the results from photographs to a map base. Topographic sheets with a lightened map load, photoplans or photomaps at a corresponding scale are used as a map base for the compilation of soil maps.

4. In the preliminary office period the work begins with the collection and systematizing of large- and medium-scale soil maps, sheets of the State Soil Map, materials from aerial and space surveys, and collection and study of sources in the literature for the investigated region.

5. Due to the fact that in the agriculturally exploited territories of the country the materials of the State Soil Map contain thorough data on the structure of the soil cover, in a generalization of large- and medium-scale soil maps with the use of space materials there is a marked increase in the role of preliminary office work on both areal and genetic interpretation of soils.

In the case of territories well supplied with soil mapping materials, the central place in the method for work on the compilation of small- and medium-scale soil maps with the use of space photographs is occupied by a scientifically sound generalization of the soil cover and the implementation of a high-quality synthesis of available soil data. In this connection full use should be made of one of the principal advantages of space methods, specifically the possibility of using them in an analysis of the soil cover in close relationship to other environmental components; due to the great field of view of the space photographs and the coverage of considerable areas when they are used there is a considerable increase in the role of physiographic synthesis of natural phenomena and features, including soils.

6. Work on the compilation of medium- and small-scale soil maps with the use of space photographs begins with their orientation and tie-in to topographic sheets of a corresponding scale, sheets of the State Soil Map and available medium-scale soil maps; the orientation and tie-in of space photographs is accomplished reliably by making use of elements of the oro-hydrographic network.

7. The first stage in the compilation of medium- and small-scale soil maps from space photographs is their use in carrying out areal interpretation of soils employing stereoscopic and optical-electronic instruments. Applying interpretation criteria (tone, photoimage pattern, character of relief,

etc.) it is possible to discriminate the boundaries of soil units on space photographs. The experience available in our country shows that in the steppe, dry steppe and desert zones on small- and medium-scale space photographs it is easy to interpret amidst zonal types (chernozems, chestnut soils, brown desert-steppe soils, gray soils) soils of the hydromorphous series: meadow-chestnut, meadow-chernozem, etc.; sandy soils and sands (ridged, barchan, hilly); soils formed on different soil-forming rocks; alluvial and ancient alluvial, meadow and meadow-swampy; present-day and ancient irrigated soils; eroded soils; takyrs; coastal (marsh) solonchaks, saline and meadow soils; mountain soils; on medium-scale photographs -- a complex soil cover with solonetz soils, etc. It is possible to differentiate typical chernozems with moderate humus from those rich in humus; typical chernozems can be differentiated from ordinary and especially southern chernozems; southern chernozems and dark chestnut soils can be distinguished from chestnut soils; chestnut soils can be differentiated from brown desert-steppe soils; a complex soil cover of the dry steppe zone and brown desert-steppe solonetz-like soils can be differentiated from solonchak-like soils, etc. Clayey and clayey loam, sandy loam soils and soil of sandy mechanical composition cannot be interpreted or are determined doubtfully; southern chernozems and dark chestnut soils, species differences of soils, etc. fall in the same category.

8. When using materials from a multizonal space survey it is necessary to use color synthesized photographs or black-and-white photographs in the red zone with additional information obtained from photographs taken in the IR and blue-green spectral zones. In the case of soil units not clearly expressed (visually) on the photographs considerable help can be obtained by the use of image analyzers of the "ISI," "Kvantimet-720," "Densitron" and other types which with the aid of corresponding densitometric units emphasize tonal differences in the color or black-and-white scale of soil cover images.

9. The results of areal interpretation of soils by the optical or mechanical method are transferred from the photographs onto the sheets of topographic maps and are tied-in to relief elements and the results of interpretation on adjacent photographs. Thereafter the soil areas on the space photographs obtained in optically generalized form for the corresponding survey scale are compared with the soil units on the State Soil Map. A diagnostic interpretation of the soil cover is made on the basis of this comparison. There can be two principal variants. The first is when the photoimage detail of the soil cover on space photographs (or some of them) is less than on the sheets of the State Soil Map. In this case the soil map data are used for an interpretation of soils on the space photographs and their subsequent use for the compilation of general soil maps. The second case is when the accuracy in discriminating soil units and degree of detail of the soil cover photoimage and its structure on the space photographs (or on some of them) are more detailed than on the sheets of the State Soil Map. In this case, on the one hand, there is a refinement of the content and detail of this map (on the basis of space interpretation data),

and on the other hand, for a diagnostic identification of the soil units discriminated from space photographs use is made of data from a medium-scale mapping of soils. In such cases it is possible to use the results of generalization of data from large-scale surveys carried out earlier or made directly in the course of compilation of small- or medium-scale soil maps from space photographs.

10. The stage of generalization of materials from large-scale soil maps (to medium scales 1:50,000-1:100,000 and 1:200,000), to the level of regional soil maps, must be carried out with the use of aerial photographic surveys at a scale of 1:25,000-1:30,000. In this stage there is refinement and correction of soil units on the basis of aerial photographs and an initial objective generalization of the soil cover with a reflection of the nature of the soil textures shown on the photographs. The generalization, which begins with a generalization of the map legends, is carried out on the principle of the similarity of soils in genesis and productive significance. It is expressed in a combining of small soil units into larger units, the compilation (taking the soil aerial photographic image into account) of new generalized units, including soil combinations, complexes and mosaics. The minimum unit for soils having clear boundaries and different genesis is 25 mm^2, for units having sharp boundaries and similar genesis -- 50 mm^2, for soils with gradual transition boundaries -- 100 mm^2.

When discriminating complex units from aerial photographs there is refinement of their percentage content of secondary and tertiary components, taking taking into account the general subdivisions for their discrimination: up to 10%, from 10 to 25%, from 25 to 50%.

11. The process of generalization and conversion from the content of soil maps of a larger scale to a medium or smaller scale with the corresponding use of aerial and space photographs should be as 1:2 or 1:3, that is, from a scale of 1:25,000-1:50,000 to 1:100,000-1:200,000, then to 1:300,000 or 1:500,000 and finally to maps at a scale of 1:1,000,000. This will make possible the most complete and precise retention of the characteristics of structure of the soil cover in individual natural regions appearing on photographs and reflection of the geographical similarity of the soil cover in the investigated territory.

In the compilation of small-scale soil maps from space photographs individual large-scale soil maps of farms and medium-scale maps of regions selected for characteristic natural-geomorphological regions can serve as inserted "keys" necessary for the compilation of more complete and informative maps, taking into account the structure of the soil cover.

12. On the basis of areal and genetic interpretation of space photographs, employing materials from earlier soil investigations and sheets of the State Soil Map, during the preliminary office period there is compilation of medium- or small-scale soil maps and the places and routes for partial checking of the content of these maps in the field are selected.

13. During the field period for soil mapping, with the use of space photographs, there is a general familiarization with natural conditions, soils and their field interpretation along the reconnaissance route. Doubtful sectors of the soil map are checked and refined, a series of primary soil profiles is prepared and materials are collected for the compilation of additional maps and cartograms. Stable interpretation criteria are established for the soil cover. Soil samples are collected for carrying out genetic analyses and studying the reflectivity of soils.

As a result, the final compilation of the soil map with an appropriate legend is finalized in the field.

14. In the office post-field period the soil map is put into its final form and an explanatory note for the map is prepared. The results of the office and field interpretation of soils are formalized in the form of soil interpretation keys, based on space photographs, composite tables and indicators of soil interpretation criteria and an explanatory text devoted to the peculiarities of their interpretation applicable to definite natural and technical survey conditions.

Effectiveness of Compilation of Soil Maps from Aerial Photographs

The matter of the effectiveness of use of materials from an aerial photographic survey for soil mapping will be examined in the example of compilation of a large-scale soil map of the "Krasnyy Oktyabr'" kolkhoz in Kurmanayevskiy Rayon of Orenburgskaya Oblast and medium-scale maps of three farms in the territory of the Mongolian People's Republic.

The soil cover of the investigated sector of the territory of Orenburgskaya Oblast was represented by southern (ordinary, terraced, with reduced effervescence, solonetz-like) chernozems, of different mechanical composition, formed on different soil-forming rocks, meadow-chernozem soils, steppe and meadow-steppe solonetz soils and alluvial soils. The use of materials from an aerial photographic survey was effective for this territory, complex in its soil geography (it is in the third category of difficulty). In the course of the work this assumption was completely confirmed. In order to characterize the soil cover (area 11,900 hectares, survey scale 1:25,000) a total of 336 test pits were dug, of which 235 were primary (depth 150-200 cm). This number, 1 test pit each 50 hectares, corresponds to the norms for the number of test pits per unit area in dependence on survey scale and the terrain category appropriate for soil cover complexity.

However, not all the soil units were characterized by test pits. A number of soil units having a similar photoimage on the aerial photographs (pattern, tone) and situated under uniform relief conditions were characterized on the basis of extrapolation of data. The sites for the digging of test holes (primary and secondary) in the terrain and the density of the reconnaissance lines were determined by the peculiarities of the soil photoimage on the photographs and photoplan with contours, which was used as an up-to-date base.

The use of aerial methods indicated that under the conditions of this natural region, southern chernozems, southern terraced chernozems of medium and small thickness, meadow-chernozem and alluvial soils are interpreted with great effectiveness. On water divides there is reliable discrimination of homogeneous and complex soil units with the participation of solonetz soils. Southern chernozems formed on different rocks, thin gravelly chernozems and steppe solonetz soils were doubtfully discriminated. On the photoimage it was impossible to discriminate southern clayey, heavy clayey loam and clayey loam chernozems and meadow-chernozem soils of different degrees of leaching, etc., that is, soils of close taxonomic ranks, the characteristics of which are not manifested significantly in the optical properties of soils, were not discriminated on the photoimage.

The use of aerial photographs made it possible to detect a number of reliable interpretation criteria for the mapping, on their basis, of such peculiarities of the soil cover important for production as discrimination of areas subject to deflation, areas of different degrees of water erosion, areas with complexes with different quantities of solonetz on old cultivated lands and areas with different types of intraunit soil nonuniformity.

Thus, for the territory of the dry steppe zone there was found to be a considerable effectiveness of use of aerial methods in the large-scale mapping of soils. It is expressed in a reduction of the number of test holes by a factor of 2-3 with retention of the necessary accuracy in the discrimination of soil units, a deeper study of the soil cover and its structure by means of primary and secondary test holes, the number of which is not lower, but even higher than the necessary norms; on the soil map there is objective expression of characteristics of the soil cover which are of importance for production. The use of aerial methods made it possible with a high accuracy (in sectors where the soils were interpreted reliably the units were discriminated with topographic accuracy) and completeness to map the soil cover and compile a soil map objectively reflecting the soil resources of the investigated region.

The use of aerial methods is still more effective in the compilation of medium-scale soil maps. We will examine the use of aerial photographs in the soil mapping of three farms in the Mongolian People's Republic, which was carried out during 1971-1974 jointly by L. P. Rubtsova and G. A. Shershukova under the direction of N. A. Nogina. When this work was done use was made of the reconnaissance-"key" survey method with the compilation of a preliminary soil interpretation map on the basis of aerial photographs during the office period for the entire territory of the farm. The number of test pits and "key sectors," as well as the density of the field reconnaissance lines, was different in dependence on the complexity of the soil cover in the investigated region and its interpretability on aerial photographs.

In a soil survey at a scale of 1:100,000 of the "Tuvshrulekh" farm, located in the wooded steppe zone, topographic maps at a scale of 1:100,000 and aerial photographs at a scale of 1:60,000 were used as bases. A comparative analysis of these materials indicated that under mountainous conditions the relief image on the aerial photographs is highly distorted and it is difficult to interpret the soil cover through forest vegetation. On the other hand, topographic maps in great detail convey the nature of the relief (steepness, exposure, length of slopes) of a mountainous territory. In a steppe lowland part of the farm the use of the tone and pattern of the photoimage on the aerial photographs made possible a reliable discrimination of meadow-chestnut and meadow solonchak-like soils associated with flat intermontane basins which on the topographic maps had a uniform pattern of the contour lines. On the other hand, smoothed ridges with chestnut soils, clearly noted on the topographic map, were sometimes poorly traced on aerial photographs.

In order to characterize the soil cover 358 test pits were dug in the four man-months of the survey. Computations indicated that for the third category of difficulty, to which the investigated territory of the farm was assigned (norm — 32,000 hectares per month), the soil map was compiled within the limits of the existing work norms for this survey scale (1 test hole per 400 hectares).

The somewhat greater number of test holes dug in this territory in comparison with the adopted norms explains the increased accuracy of the map and its more complete content as a result of use of aerial methods. With respect to the accuracy and volume of soil information (due to the use of data from aerial photographs at a scale of 1:60,000) the soil map for the "Tuvshrulekh" farm approaches a scale of 1:50,000. As a result, it can be assumed that the final compilation of the soil map at a scale of 1:100,000 is twice as complete and is of a higher quality in content due to the use of aerial methods.

At the "Unzhul" farm, typical for the steppe zone of the Mongolian People's Republic, a scientific-production soil survey at a scale of 1:200,000 was carried out over an area of 319,000 hectares using topographic maps at a scale of 1:100,000 with the use of aerial photographs at a scale of 1:32,000. In natural respects the analyzed territory can be assigned to the dry steppe with the widespread occurrence of chestnut soils. The reconnaissance-key research method was employed when carrying out soil map work. In the preliminary office period over the entire survey area a preliminary soil interpretation map was compiled (with the use of a stereoscope and aerial photographs). The results of the interpretation were transferred to a topographic base at a scale of 1:100,000.

An analysis of the photoimage of this territory made it possible to divide it into three major soil-geomorphological regions and the valley of the Tola River, for which four "key" sectors were selected, each of which characterizes a typical dry steppe landscape. During the field period work on the mapping of the territory (after a general reconnaissance) was begun from these sectors (each with an area 30-60 km^2) for the purpose of detecting from photographs at a scale 1:32,000 soil cover structures. Work in the key sectors was done using a denser network of test pits than elsewhere. In a reconnaissance survey (distance between lines 4-5 km) use was made of the principle of extrapolation of collected data.

A total of 570 test holes were dug in the field period in compiling a field compilation of a soil map at 1:100,000, which in content had information from aerial photographs at a scale of 1:32,000. In order to support a final map at a scale of 1:200,000, in accordance with the third category of difficulty, to which the investigated territory was assigned, the number of test pits dug was somewhat greater than according to the adopted norms. This is related to the more complete map representation of the content of the soil cover and its structure when using aerial photographs. In general, aerial methods increased the quality of the investigations made and the soil map and the completeness of its content was doubled or tripled.

Soil interpretation keys or samples were prepared during the final office period; the basis for these was the "key" sectors. It was established that the specific nature of soil interpretation in this territory is related, on the one hand, to the fact that this is a natural region with clearly expressed features of macro- and mesorelief, and on the other hand, that this is a zone of steppe virginland vegetation, poorly affected by agricultural exploitation. Accordingly, the basis was an indirect interpretation of the soil cover, accomplished through the direct image of relief and steppe vegetation.

In the semidesert zone of the Mongolian People's Republic a soil survey at a scale of 1:200,000 was carried out in the territory of the "Bulgan" farm. As a base for compilation of the soil map use was made of sheets of a topographic map at a scale of 1:100,000 and aerial photographs at a scale of 1:32,000. The survey was made over a two-year period. During the first year a total of 360,000 hectares was mapped of a total area of 830,000 hectares. The good surface exposure of the territory (the projective coverage of the soil surface by vegetation here is from 3-4 to 12-20%) made it possible to have a very clear contrasting image of the soil cover on the aerial photographs.

The method for compiling the soil map was as follows. During the preliminary office period aerial photographs were obtained on which after delineating the work areas by means of a mirror-lens stereoscope it was possible to carry out visual-instrumental soil interpretation. On the basis of an analysis of the aerial photographic image for the first year of the soil survey it was possible to define five "key" sectors taking in different geomorphological territories: a foothill area, a sloping proluvial-denudational plain with absolute elevations of 1,700-1,350 m (here three "key" sectors were selected) and an erosional-denudational plain of an average level with absolute elevations of 1,300-1,100 m (two "key" sectors).

In the preliminary office period, using aerial photographs for the entire survey area, it was possible to compile a preliminary soil interpretation map with the soils being transferred from aerial photographs to sheets of a topographic map at a scale of 1:100,000.

During the field period work on compilation of the soil map began from the "key" sectors, each of which covered an area of 25 km^2. Work in these areas for study of the soil cover, its structure and the different character of the photoimage was carried out using photographs at a scale of 1:32,000 and a grid of test pits of increased density (up to 1-2 km). Thereafter, a reconnaissance soil survey was made with the distance between reconnaissance lines being 4-5 km. The investigations indicated that for the territory of the foothill plain it was possible to extrapolate successfully the interpretation criteria for brown desert-steppe and watershed soils determined in "key" sectors to a distance of 50 km or more. In the territory of the erosional-denudational plain it was easy to determine different forms of sand (barchan, ridged, hilly) from the photographs and extrapolate them for tens and hundreds of kilometers. It was easy to determine highly eroded sectors of the soil cover with surface outcrops of Tertiary reddish rocks and erosional deflation basins.

According to the existing production norms, for a scale of 1:200,000 one worker is assigned 120,000 hectares per month. Therefore, the work area of 360,000 hectares called for 3.5 man-months. Taking into account that a field copy of the map was compiled at a scale of 1:100,000, the work productivity was twice as great. This effect during the field period is attributable, on the one hand, to the fact that a soil map was compiled first, and on the other hand, to the use of materials from an aerial photographic survey with good interpretability of the soil cover. A total of 376 test pits were dug for compilation of an interim soil map during field work. According to the existing norms (1 test pit per 1,200 hectares) for territories of the second category of difficulty, to which the lands of the farm were assigned, it would be adequate to have 290-300 test pits. The somewhat greater number of soil test holes dug is attributable to the high information content of the aerial photographs with respect to the photoimage of the soil cover and its structure. The following year this soil survey work was continued; full use was made of the earlier experience in office and field work in this territory. About 700 soil test pits were dug in an area of 830,000 hectares during two field seasons. The use of aerial photographs made it possible to create a precise soil map, complete in content. Somewhat generalized information from aerial photographs at a scale of 1:32,000 was used in creating a field compilation of a soil map at a scale of 1:100,000. If it is taken into account that the final compilation of the soil map was at a scale of 1:200,000, the completeness of the content and the quality of the map, as a result of the use of aerial methods, increased not less than two- or threefold.

The scientific-productive investigations which were made indicate a considerable effectiveness of use of aerial methods in soil science in the study and mapping of the soil cover. A further increase in effectiveness of soil aerospace methods involves an improvement in the interpretability of the soil cover, the formulation of soil interpretation keys and an intensification of the role of preliminary office soil interpretation, and also during this period a more thorough study of the soil cover from aerospace photographs with the use of modern instruments and apparatus.

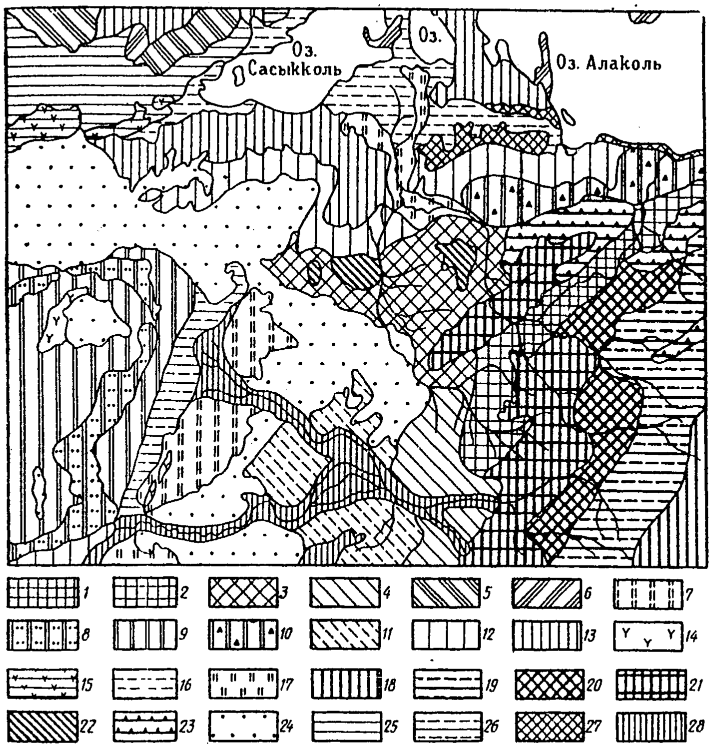

Fig. 50. Small scale soil map of the territory of the southeastern part of Kazakhstan.

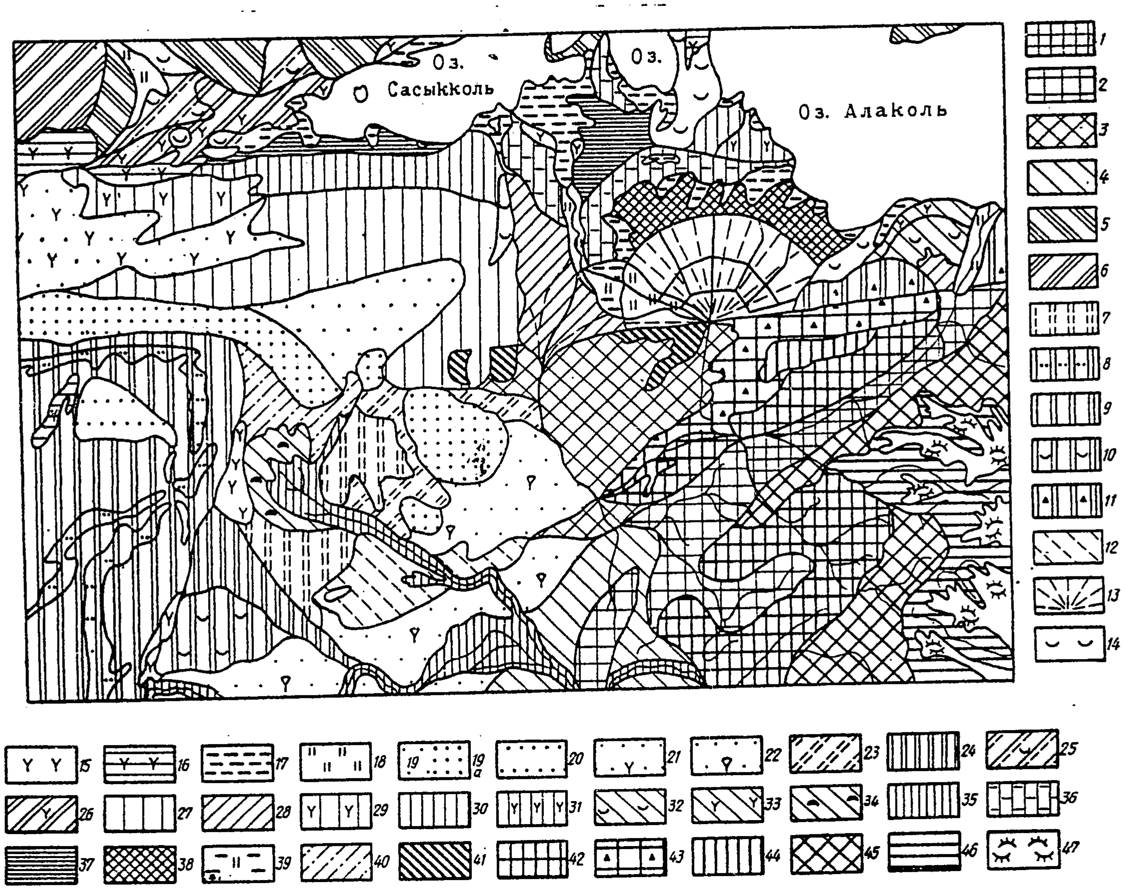

Fig. 50a. Interpretation of soil cover of territory of southeastern part of Kazakhstan from multizonal space photographs taken from the "Soyuz-22" (survey time 17 September 1976).

KEY TO FIGURE 50 (page 272): 1) medium-thick chernozems with average humus content in intermontane basins; 2) chestnut clayey loam soils; 3) light chestnut sandy loam soils; 4) light chestnut calcareous sandy loam soils; 5) brown desert-steppe sandy loam soils underlain by sandy gravels; 6) brown desert-steppe soils; 7) gray-brown desert sandy loam soils; 8) gray-brown desert sandy loam soils with outcrops of siliceous sandstones; 9) gray-brown desert solonetz-like soils; 10) gray-brown desert solonetz-like soils, locally highly gravelly; 11) gray soils with low carbonate content; 12) meadow-gray soil complex; 13) meadow solonchak-like solonetz soils; 14) solonchaks; 15) salina solonchaks; 16) meadow-swampy soils; 17) alluvial-meadow soils; 18) mountain-meadow alpine soils; 19) mountain-meadow subalpine soils; 20) podzolized mountain chernozems; 21) leached mountain chernozems; 22) mountain chestnut soils; 23) outcrops of crystalline rocks; 24) ridged-hilly sands; 25) brown meadow-steppe soils, solonchaks and desert solonetz soils; 26) solonchaks and residual solonetz soils; 27) meadow solonchak-like soils, meadow solonchaks, meadow solonetz soils; 28) meadow solonchak-like and meadow solonchaks.

KEY TO FIGURE 50a (page 273): 1) medium-thick chernozems with average humus content in intermontane basins; 2) chestnut clayey loam soils; 3) light chestnut sandy loam soils; 4) light chestnut calcareous sandy loam soils; 5) brown desert-steppe sandy loam soils on sandy pebbles; 6) brown meadow-steppe soils; 7) gray-brown desert sandy loam soils; 8) gray-brown desert soils with outcrops of siliceous sandstones; 9) gray-brown desert solonetz-like clayey loam soils; 10) gray-brown desert solonetz-like clayey loam and sandy loam soils; 11) gray-brown desert solonetz-like, locally highly gravelly; 12) gray soils with low carbonate content; 13) irrigated meadow-gray soils; 14) meadow solonchak-like solonetz soils; 15) solonchaks; 16) salina solonchaks; 17) meadow-swampy soils; 18) alluvial-meadow soils; 19) sands; 19a) moist sands; 20) sands on ancient alluvial deposits; 21) sands and solonchaks; 22) sands, desert takyr-like soils and solonchaks; 23) gray-brown desert sandy loam soils and desert residual solonetz soils; 24) gray-brown desert soils with participation of solonetz-like soils and desert solonetz soils; 25) brown meadow-steppe soils, meadow solonchak-like solonetz soils, solonchaks; 26) brown meadow-steppe soils, solonchaks, meadow solonchak-like solonetz soils; 27) meadow-gray soil complex, meadow solonchak-like solonetz soils; 28) meadow-gray soil complex, meadow solonchak-like solonetz soils on ancient alluvial-proluvial deposits; 29) meadow-gray soil complex, solonchaks, meadow solonchak-like solonetz soils; 30) meadow solonchak-like, meadow solonchak-like soils; 31) meadow solonchak-like, meadow solonchak-line solonetz soils, solonchaks; 32) meadow solonchak-like, meadow solonchak-like solonetz soils on ancient alluvial-proluvial deposits; 33) meadow solonchak-like soils, meadow solonchak-like solonetz soils and solonchaks on ancient alluvial-proluvial deposits; 34) meadow solonchak-like soils, desert solonetz soils and solonchaks; 35) meadow solonchak-like soils, alluvial soils and meadow solonchaks; 36) meadow solonchak-like and meadow-swampy soils; 37) meadow solonchak-like and meadow-swampy soils, meadow solonchak-like solonetz soils and meadow solonchaks; 38) meadow solonchak-like soils, meadow solonchaks, meadow solonchak-like,

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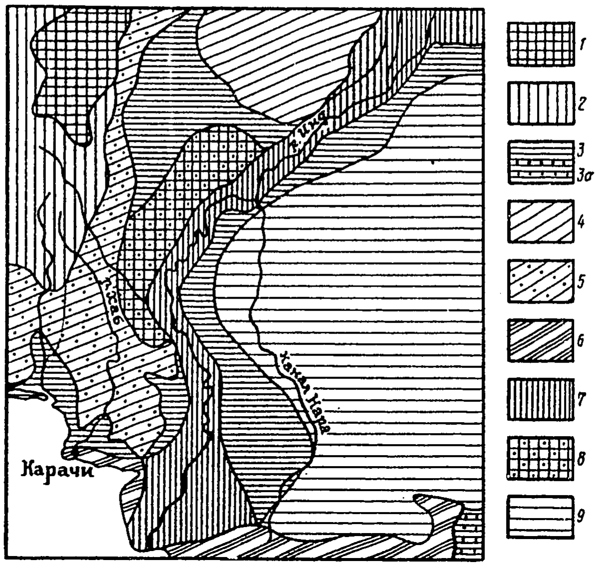

Fig. 51. Fragment of soil map of territory of lower course of Indus River. Scale 1:6,000,000 (see soil map of Asia): 1) mountain cinnamon; 2) mountain gray soils; 3) typical desertified gray soils of ephemeral steppes; 3a) same, with participation of sands and saline soils; 4) typical gravelly desertified gray soils of ephemeral steppes; 5) typical desertified gray soils of ephemeral steppes and reddish soils of deserts; 6) solonchaks; 7) floodplain alluvial; 8) floodplain alluvial and inundated (rice) soils; 9) sands

Table 46

Effectiveness of Use of Space Photographs in Special Mapping

Types of mapping work	Decrease in work output, in %		
	original compilation	editing	compilation
Preparation of special maps	50-60	20-30	10-20
Revision of special maps	60-70	40-50	30-40

KEY TO FIGURE 50a (continued): meadow solonchaks, meadow solonchak-like solonetz soils on ancient alluvial and proluvial deposits; 39) alluvial and meadow-swampy soils on alluvial deposits; 40) residual solonetz soils and solonchaks; 41) mountain chestnut soils; 42) leached mountain chernozems; 43) leached mountain chernozems and outcrops of crystalline rocks; 44) leached and podzolized mountain chernozems; 45) podzolized mountain chernozems; 46) mountain alpine and subalpine soils; 47) mountain alpine and subalpine soils, snow covered.

Effectiveness of Compilation of Soil Maps from Space Photographs

The use of space materials makes it possible to increase effectiveness in the compilation of soil maps. According to data published by Yu. G. Kel'ner and G. N. Romankevich, specialists at the "Priroda" State Scientific-Production Center of the Main Administration of Geodesy and Cartography of the USSR Council of Ministers, the saving of work expenditures in different stages of compilation and revision of special maps from space photographs is from 10 to 70% (Table 46).

These data show that the economic effectiveness of use of space photographs in special, including soil, mapping, is quite high. It will be still higher as the methods and instrumentation of a space survey continue to improve and as the mapping method is improved.

The real annual economic effect from the use of space materials in the study of soils and special mapping in the United States and Canada even today is reckoned in the tens of millions of dollars (Table 47).

The use of space photographs in the study of soil resources in soil mapping increases the effectiveness of work of the soil scientist with respect to the accuracy and completeness of the investigations.

A small-scale soil map was compiled for the territory of southeastern Kazakhstan using multizonal space photographs from the "Soyuz-22." Sheets from a medium-scale soil map of Kazakhstan were used in the interpretation and in the compilation of this map. Areas of sands are shown more precisely and completely on the map compiled from the photographs; areas of soils situated on the alluvial fans of mountain rivers and in the territories adjacent to them were clearly defined cartographically with topographic accuracy. On a photograph in the IR zone there was more reliable plotting of an area of meadow-swampy and alluvial meadow soils, etc.

The soil map compiled as a result of interpretation of multizonal photographs was compared with a small-scale soil map (the map scales were similar) available for this territory. The analysis indicated that the interpretation of the soil cover from space photographs made it possible to compile not only a more precise, complete and detailed (48 soil subdivisions and their complexes were discriminated instead of the 26 determined earlier), but also qualitatively new map, most completely reflecting the principal geographic patterns of structure of the soil cover in this territory of southeastern Kazakhstan (Fig. 50, 50a).

A similar soil mapping investigation was carried out in the territory of the lower course of the Indus River. A comparative analysis of the soil map of this territory with the soil map obtained as a result of interpretation of space photographs from the ERTS satellite indicated that the initial map required refinements of the boundary of mountain cinnamon and mountain gray soils, gray soils of typical desertified ephemeral steppes,

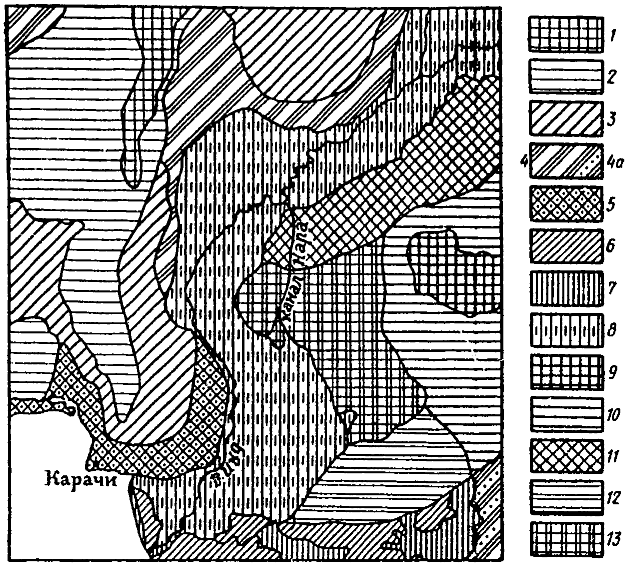

Fig. 51a. Interpretation of soil cover of territory of lower course of Indus River from space photographs taken from the ERTS-1. Soils: 1) mountain cinnamon; 2) mountain gray soils; 3) mountain gray soils and gravelly desertified typical gray soils of ephemeral steppes; 4) desertified typical chernozems of ephemeral steppes; 4a) same, with participation of sands and saline soils; 5) desertified typical gray soils of ephemeral steppes and reddish soils of deserts; 6) meadow solonchak-like and solonchaks; 7) solonchaks; 8) floodplain alluvial and inundated (rice) soils with participation of secondarily saline soils; 9) sands and gray soils of deserts; 10) sands; 11) ridged sands; 12) hilly sands; 13) deflatable sands

Table 47

Annual Saving from Use of Space Materials in 1974 (in Millions of Dollars)

Indices	United States	Canada
Agriculture:		
agricultural crops	5.6	0.3
pasture	39.7	3.0
Soils and land use	26.9	9.3
Mapping and special mapping	----	20.2

Table 48

Effectiveness of Use of Space Photographs in Refining Soil Maps (Semidesert Zone, Caspian Area; Area of Control Sectors -- 40.000 Hectares)

Soil-geomorphological region	Soils	Количество почвенных выделов на карте, составленной 1		Коэффициент детальности ($К_д$) 2		Эффективность ($Э_{цк}$), % 3	
		без космических снимков 4	по космическим снимкам 5	по участку 6	средний по карте 7	по участку 6	средняя по карте 7
Lower sea terrace of Caspian	Meadow coastal solonchak-like, meadow-swampy coastal, salina solonchaks, coastal solonchaks	5 3 6	9 8 13	1,8 2,7 2,2	2,9*	44 62 54	62
Second terrace of Caspian	Brown desert-steppe solonetz-like and solonchak-like, desert solonetz, salina solonchaks	2 2 3	8 12 9	4,0 6,0 3,0		75 83 66	
Tenteksor village	Brown desert-steppe solonetz-like, solonetz and salina solonchaks (50%)	2 1 1	52 41 37	26 41 37		96 97 97	
Emba River valley	Alluvial meadow and meadow-swampy solonchak-like, brown desert-steppe solonetz-like and solonetz	4 6 5	12 14 16	3,0 2,3 3,2		66 60 68	
Ancient delta of Ural River	Alluvial meadow, moist meadow and meadow-swampy solonchak-like, solonchaks	4 5 4	13 10 8	3,2 2,0 2,0		70 50 50	

* Except for data for Tenteksor village

KEY:

1. Number of soil units on map, compiled...
2. Detail coefficient (K_d)
3. Effectiveness (E_{ef}), %
4. Without space photographs
5. Using space photographs
6. For sector
7. Average for map

floodplain alluvial soils and solonchaks. Using space photographs with a topographic degree of accuracy it was possible to interpret an area of floodplain alluvial soils along the valley of the Indus River, constituting an important land resource of Pakistan. On the photographs it is easy to see the internal nonuniformity of the photoimage of these soils -- the presence of sectors of secondary salinization. The soil cover in the desert shows up more differentially on the space photographs. Whereas on the soil map of the lower course of the Indus River it had earlier been possible to discriminate nine soil subdivisions, after the interpretation 13 could be discriminated. As a result, the new soil map began to reflect the land resources of the analyzed territory more completely and objectively (Fig. 51, 51a).

Experience in study of the possibility of using small-scale space photographs (scale 1:1,000,000-1:2,500,000) for refining existing soil maps (of similar scales) for different natural zones indicated that the interpretability of the soil cover and the effectiveness of map compilation for the territory of the dry steppe and desert zones is several times greater than for the steppe zone.

Space photographs, as a result of their greater coverage and image generalization, for the first time made it possible to interpret and cartographically more precisely discriminate ancient deltas and their soil cover on maps.

It was demonstrated on the basis of investigations with the use of multizonal space photographs that in small-scale soil mapping there can be a marked improvement in the principle of geographic similarity of the image of soils and their complexes on a map of soil cover structure in the terrain. In most cases the geographic base for the compilation of soil maps is topographic maps, on which there is no image of the soil cover. Accordingly, in its generalization without the use of space photographs the specific structure of the soil cover of individual natural regions and geographic zones is represented incompletely. One of the principal advantages of use of space photographs in the field of soil mapping is the effect from a space classification of the soil cover. This theoretical principle is particularly important because soil mapping is a special method for spatial investigation and representation of structure of the environment.

In conclusion we will cite data on investigations of the effectiveness of space photographs for compilation of a small-scale soil map of the Caspian area (Table 48).

Promising Directions in the Use of Aerospace Methods for Study of Soil and Agricultural Resources

In soil science and agriculture, taking into account the needs of our country in the immediate future, it is necessary to develop the following fundamental directions in the field of use of aerospace materials.

1. Compilation and correction of oblast and republic soil maps, sheets of the State Soil Map of the USSR, compilation of the soil map of the USSR at a scale of 1:2,500,000. Compilation and refinement of a soil map of the world with the use of a great number of color and black-and-white photographs taken from space for the territory of foreign countries; in this work it is important to investigate the process of optical generalization of the soil cover image on photographs and determination of the possibility of interpreting types, subtypes, genera and possibly, species of soils. Aerospace photographs make it possible to map soils of different regions with a greater accuracy and completeness with respect to content and representation of the soil cover structure. Accordingly, they make it possible to compile soil maps at medium and small scales at a qualitatively new level.

2. Development of a new type of soil maps. Two new soil mapping solutions are possible here.

Compilation of photosoil maps at a scale of 1:100,000-1:1,000,000 on which the soil content of the map will be shown against the background of the photoimage of space photographs.

Compilation of synthetic soil maps; the materials from a space survey clearly reflect the soil cover and its interrelationship to the environment, which makes them an important base for synthesis of phenomena in a study of the soil cover and compilation of synthetic soil maps.

3. Study of the composition and properties of soils on the basis of remote sensing. Dynamic measurement of soil temperature and moisture content in different natural regions with the use of IR radiometers. Determination of the humus content in surface soil horizons by means of scanning detectors. By the use of remote investigation methods there can be automatic compilation of thermal maps of the terrain, maps of soil humus and moisture content.

4. Investigation of the dynamic properties of soils and preservation of their fertility. The formulation of investigations in this direction is related to a peculiarity of an aerospace survey of the earth's surface -- the possibility of a rapid and regular repetition of the survey. This is especially important in judging the rapidly developing processes transpiring in soils.

Aerospace materials can be used in solving the following problems: a) determination of the intensity of water and wind erosion; mapping of eroded soils from space photographs and ascertaining the effectiveness of protective measures for the conservation of soils; determination of centers of propagation of sand and dust storms; b) detection of areas of soils disrupted by industrial development and monitoring of measures for their restoration; c) investigations of shore destruction of canals and reservoirs, determining areas of inundation of soils in the zone of their activity; d) determining the resources of swampy, eroded, saline lands, especially in inaccessible regions of the country; e) development and improvement of the method for the study of soils requiring melioration from space survey photographs; determination of areas of seasonally and periodically saline soils; monitoring of the functioning of irrigation and drainage systems using materials from repeated space surveys; inventorying the state and change in the quality of soils and areas of cultivated lands under the influence of irrigation and drainage improvements; detection of overdried lands; ascertaining the nature of moistening, times of the next irrigation and leaching.

Under conditions of meliorable, drainable and irrigable lands it is promising to make use of aerospace methods for solution of the following practical problems in agriculture: determination of sown areas; determining and inventorying present-day drained and irrigated areas; determination of the general condition of agricultural crops in drained, irrigated and nonirrigated areas; detection of possible anomalies in the development of agricultural crops caused by different factors (soils becoming swampy, soils becoming saline with detection of regions of secondary salinization, absence of drainage, diseases and predators of agricultural crops, inadequacy of nutrients in the soil, etc.); determination of areas with leakage from irrigation canals; observations of implementation of the plan for agricultural melioration; evaluations of different methods for drainage and irrigation, their influence on the development of agricultural crops; determination of soil fertility and yield of agricultural crops under irrigated conditions and on drained lands.

5. Inventorying of different types of land use and methods for their cultivation. Determination of their quality for the purpose of ensuring rational use of lands and creation of conditions for increasing their effectiveness. Use of space photographs for compiling maps of the types of use and preservation of lands with clarification of long-term soil resources. The widespread use of aerospace materials will make possible not only the organization of a rigorous inventory of land use, but also the finding of additional land resources for increasing the production of agricultural crops.

6. Soil-agricultural regionalization of the territories of our country and foreign countries. Soil-melioration regionalization of lands in the irrigated zone and drained territories. Soil-erosion regionalization. Use of space materials in soil regionalization will favor a deeper study of the land resources of our country.

In addition to strictly soil problems, the application of space photographs in branches of agricultural science bordering on soil science is of great importance for solution of fundamental agricultural problems. Among these we can mention the following.

7. Detection of areas of different agricultural crops and determination of their yield. This direction in research is one of the key directions in the aerospace agricultural program. Maps of food and forage crops can be compiled for different periods in the growing season. It is possible to establish the relationship between crop yield, soil fertility and natural terrain conditions. In the future provision must be made for carrying out an automated survey of agricultural crops from space.

8. Determination of cultivated hayfields and pastures and their condition. Mapping and evaluation of the productivity of natural hayfields and pastures for soil-geographic zones of the country. Determination of the interdependence of natural vegetation, soils, geology, relief and hydrography. Determination of the principal types of meadows. Determination of hayfields and pastures requiring superficial or radical improvement in the natural grass stand. The problem of generalization of the plant cover and the characteristics of its interpretation from space photographs.

9. Detection of centers of damage to agricultural crops. Determination of an early diagnosis of diseases of grain crops, cotton, sunflowers, potatoes, sugarbeets and other agricultural crops. Determination of centers of contamination of agricultural crops and their mapping. Determination of the relationship between the diseases of agricultural crops, nature of the soil cover and natural conditions.

10. Methods for the compilation of maps of land use areas, maps of the boundaries of land use by agricultural enterprises, cadastral maps from space materials. On the basis of study and mapping of different land use areas and organization of agricultural production, use of space photographs in discriminating territories with different types of agricultural production.

SUMMARY

During the 50 years from the time of formation and development of aerial methods for the study of soils there have been fundamental investigations of the interpretation and mapping of the soil cover with the use of black-and-white and color spectrozonal photographs in different soil-geographic zones of our country.

A qualitatively new jump in the study of the soil-agricultural resources of the earth has occurred during the last 5-10 years in connection with the use of space and multizonal aerospace research methods. Both photographic and photoelectronic methods have been successfully developed.

The investigations which have been carried out with the use of aerospace methods for the study of soils and generalization of the Soviet and foreign experience have made it possible to obtain the following results.

1. It has been established that aerospace methods are of great importance for objective (reliable), precise and thorough routine collection and interpretation of information on land (soils-agricultural) resources. Space photographs, covering extensive territories of the earth, make it possible to see and map the latitudinal and vertical zonality of soils and also to compile and refine soil maps of medium and small scales which are more complete in content. This effect is 1.5-2 times greater for the dry steppe and desert zones in comparison with the methods used earlier.

On space photographs there is an objective optical generalization of the soil cover, and as a result the concept of simple and complex integration has been introduced into space interpretation theory. The first is characteristic for the reflection of combinations of soils on photographs, and the second -- for the photoimage of soil complexes.

Space methods constitute an important tool for monitoring the state of soils for the purpose of preserving and predicting the soil medium and soil fertility. On photographs there is reliable interpretation of irrigated lands from the contrast in color of moist irrigated and dry unirrigated soils. Due to the extensive coverage of space photographs and the generalization of details on them there is a clear representation of sectors of the soil cover of modern deltas and it is possible to interpret soils of ancient river deltas of different age which earlier could not be clearly detected cartographically by other methods.

Space photographs are used in agricultural interpretation for ascertaining the processing of soils and for determining the type of agricultural crops.

We have introduced the concept of the effect of space classification of the soil cover into the theory of soil interpretation.

2. An examination of the theoretical principles of interpretation of the soil cover from aerospace materials indicated that at the present time the basic method is the visual-instrumental method for investigating soils in which there is the most complete use of the logical inferences of the interpreter and a quantitative analysis of the photoimage of the photographs is employed.

A quantitative visual-instrumental method has been proposed for the interpretation of soils and agricultural crops (with use of a "Kvantimet-720" image analyzer) using aerospace photographs. The interpretability of features is evaluated in relative units from the difference in the level of the gray tone of adjacent soil and vegetation units. A quantitative scale for evaluating the degree of interpretability of objects has been proposed within the limits of the instrument operating range (64 levels of gray tone). Using this instrument, on the photographs amidst visually seemingly homogeneous almost white, gray or almost black images of soils or crop areas, it is possible to detect tone differentiation, which is of great importance in the mapping of soils. A machine analysis of photographs made using the "Kvantimet-720" made possible a differentiated, precise and objective compilation of soil maps.

The objectives of soil interpretation are, first of all, the detection of genetic varieties of soil cover on aerial and space photographs and their outlining, and second, determination and analysis of the soil units detected on the photographs. An important and independent task is the extrapolation of the soil results to similar territories. An analysis of the complex of interpretable criteria (direct -- tone, color, texture, shape, size of the soil units; indirect -- characteristics of relief, hydrography, vegetation, man's agricultural activity) is the basis for the successful interpretation of soils.

A classification of textures (patterns) of the photoimage of the soil cover on aerial and space photographs, a necessary condition for reliable interpretation of soils, was developed. In connection with the automation of interpretation a new direction is developing -- study of the language of the photoimage of photographs by the recognition of characteristic structures. The basis for the classification of textures of the soil cover image is the objective difference in the patterns registered on the photographs, in dependence on the genetic soil varieties to which they correspond. This principle makes it possible, in an extrapolation process, to use the discriminated textures of the photoimage for a successful diagnostic interpretation of the soil cover of similar territories.

A study of the spectral reflectivity of soils in the steppe and dry steppe zones, taking into account the total reflection coefficient and in a definite narrow spectral zone, indicated that the lesser the humus content in the soil, the greater the content of carbonates, the lighter the mechanical composition, the greater is the reflectivity and the lighter is the soil image on the photographs. The calcareous nature of the soils and rocks is manifested quite sharply in the blue-green spectral zone where the soils usually have low reflection coefficients. A joint analysis of the reflectivity of soils and multizonal photographs made it possible to diagnose the soils developed on different rocks.

Color is a reliable interpretation criterion for soils. Photographs of the SN-6, SN-23 and SN-8 types were the best of the color spectrozonal materials for soil purposes.

On the basis of the extent of the soil units there is reliable discrimination of sectors with a uniform soil cover and soil complexes; on the basis of extent and shape it is possible to ascertain different elements of gully erosion. The extent and shape of the soil contours are governed by the nature of the relief and serve as a component part of the different textures of the photoimage of the soil cover.

The largest relief elements (geotexture and morphostructure of the earth's surface) are shown in optically generalized form on medium- and small-scale space photographs. Morphosculptural elements, which constitute the basis for indirect interpretation of soils on the basis of aerial survey materials, frequently cannot be seen on space photographs.

It was established in the interpretation of soils through cultivated vegetation that dense full-grown plantings conceal the surface and the structure of the soil surface. However, in a number of cases they can emphasize the differences in the degree of erosion, moisture content, solonetzification and fertility of soils. Grain crops from the sprouting phase to the phase of stem extension and young tilled crops exert virtually no influence on the soil photoimage. The soil cover of steppe areas is reliably interpreted through meadow and steppe virgin land vegetation on the basis of tone and especially the pattern of its photoimage on photographs.

3. The specific nature of use of interpretation criteria in the interpretation of soil-agricultural features from space photographs involves the following.

In the interpretation of soils from space photographs, due to the great areal coverage of considerable territories, there is a marked increase in the role of physiographic synthesis -- allowance for indirect criteria, interrelationships and intercausalities of all environmental components.

When using tone it must be remembered that on space photographs it is common to have to contend with the integral phototone of the soil cover image.

On space photographs there is clear interpretation of a spotty form of soil areas with a contrasting soil cover (solonchaks, meadow-swamp soils of depressions), but linear, meandering and dendritic forms are determined still more reliably. Whereas on aerial photographs there is representation of individual forms of soil units, space photographs show entire regions of similar shapes and dimensions.

On space photographs the image texture of the soil cover is also specific; it is caused by the generalization of individual details of structure of the earth's surface; it was established that the very same geometrical form of texture (pattern) on aerial and space photographs can have a different content.

4. It has been established that new possibilities for a more complete and objective interpretation of soils and areas of agricultural crops are being afforded by the use of multizonal aerial and space photographs.

Investigations have shown that when using multizonal aerial photographs the highest quality of interpretation (accuracy, completeness, reliability) of the soil cover and agricultural crops was obtained with the joint use of photographs taken in the green, red and IR spectral zones.

In the steppe zone, using multizonal aerial photographs taken in the IR region in the autumn period of a survey, it is possible to detect the greatest difference between fields of winter wheat sown in clean and occupied fallow. This makes it possible to predict its crop yield for the future year. Using autumn aerial photographs taken in the red zone there is reliable determination of typical chernozems, eroded chernozems and meadow-chernozem soils in plowed fields, as well as plantings of perennial grasses and sectors of unmown steppe amidst areas of mown steppe. Meadow-chernozem soils associated with microdepressions were interpreted through the photoimage of cultivated crops (sugar beets) on the basis of the spotty-dotted pattern on autumn photographs taken in the green zone. These could not be seen through cultivated plantings on autumn photographs taken in the red and IR spectral zones. On aerial photographs of surveys made in the early summer (June) chernozem soils were visible in all three spectral zones through the image of cultivated crops. They were not interpreted through plantings of grain crops.

In the dry steppe zone, using multizonal aerial photographs taken in the red zone, there was successful interpretation of the soil cover (dark chestnut, meadow-chestnut, solonetz) through the direct image of grain and cultivated crops. In the green and IR spectral zones it shows up less clearly or cannot be interpreted at all. Using summer and autumn photographs taken in the green and especially in the red and IR zones it was possible to determine fields of spring wheat and barley differing in crop yield by a factor of 1.5-2. Using July photographs of the IR spectral zone there is reliable interpretation of the field of grain crops in dependence on the nature of the preceding working of the soils (fallow, deep loosening and leveling). In this spectral zone there was also reliable determination of fields with different times of sowing of grain and cultivated crops and fields of bare fallow.

In the desert zone, in irrigated lands, using multispectral aerial photographs, it was possible to make reliable interpretations of gray soils and gray-brown gypsum-bearing soils of adyry (low foothills surrounding a depression), old irrigated, meadow gray soils and newly irrigated highly saline soils with the participation of solonchaks and gray sands. Amidst the sandy complexes in the blue-green zone there is reliable interpretation of barchan deflated sands, small mounds of sands, depressions between ridges with ground water at a shallow depth and masses of consolidated gray sands. Among the agricultural crops plantings of cotton and grasses (alfalfa, Sudan grass) are readily distinguished.

5. During recent years a multizonal space survey has been coming into increasingly broader use in study of the soil cover.

On one of the multizonal space photographs for the first time obtained in our country from the "Soyuz-12, for the territory of the Mangyshlak Plateau it was possible to have reliable interpretation of gray-brown solonetz-like (gray and light gray tones) and gray-brown solonchak-like (dark gray tone) soils, as well as chestnut soils in the Karatau Range.

They were poorly interpreted or not interpreted at all in the blue zone of the spectrum and had the sharpest image contrast in the yellow-orange-red (0.58-0.64μm) spectral zone. Solonchaks and sands were determined with the joint use of photographs in the blue and yellow-orange-red spectral zones.

The use of space photographs from the "Salyut-4" for the interpretation of soils in a mountainous territory indicated that the best result was obtained using color synthesized photographs and black-and-white photographs taken in the zone 0.5-0.6 and 0.6-0.7μm.

An interpretation of the soil cover of the steppe and desert zones using multizonal space photographs taken from the ERTS (United States) indicated that photographs in the range 0.6-0.7μm have the sharpest contrast of the photoimage of soils and agricultural crops. On photographs in the zone 0.8-1.1μm it is easy to interpret the channels of rivers along which alluvial soils are reliably determined. Irrigated fields are reliably determined amidst arid lands on photographs in this IR spectral range. In general, for successful soils-agricultural interpretation from multizonal photographs of the ERTS-Landsat it is necessary to make joint use of photographs in the spectral zones 0.5-0.6, 0.6-0.7 and 0.8-1.1μm.

An analysis of multizonal space photographs taken from the "Soyuz-22" indicated that the most precise visual-instrumental discrimination of soil units and a thorough image of the soil cover was obtained with the joint use of photographs in the blue-green, red and IR (0.82μm) spectral zones. A densitometric processing of the multizonal photographs taken with the MKF-6 camera made it possible to determine diagnostic spectral soil curves -- a new and important criterion for interpretation of the soil cover.

Multizonal color space photographs synthesized with the MSP-4 instrument have great possibilities. Due to the more easily distinguishable color range of the photoimage of the soil cover they give the maximum effect for both outlining soil areas and for the diagnostic interpretation of soils.

6. A new valuable source by means of which it is possible to obtain information on the radiated energy of the soils and plantings in the entire range of the electromagnetic spectrum is photoelectronic research methods. The data from a radiothermal survey in the range 0.8-3.4 cm were effectively used in studying the surface moisture content of soils.

An infrared radiometer (operating in the range 8-12μm) was used in registering several different thermal anomalies of the soil cover in the territory of the European USSR. Against the background of thermal anomalies characteristic for the territories of Steppe Crimea and the Prichernomorskaya Lowland there was clear discrimination of the colder sectors of alluvial-meadow and meadow-swamp soils of the lower reaches of the Kuban and Danube. Against the background of the warmer sectors of the Sal'sko-Manychskaya Ridge with southern chernozems and dark chestnut soils it was possible to discriminate colder sectors of the territory of the Kuma-Manychskaya depression.

Side-view radars considerably supplement other methods because this equipment operates successfully at nighttime and in the presence of cloud cover. Radar photographs have been used successfully in the recognition of soils and agricultural crops. By changing the signal direction and strength this method makes possible an approach to study of the mineralogical composition and penetration into the depth of the soil layer. The use of radar photographs in the territory of Northern Kazakhstan from the moiré pattern of a dark gray tone made it possible to determine dark chestnut sandy and sandy loam soils formed under virgin land grassy vegetation of different types; eroded soils were interpreted very clearly from the spotty-dendritic pattern. Visible in contrast on the photographs is the antierosion strip system of agriculture (fields with an alternation of cultivated crops and grasses); fields of bare fallow; fields with plantings of spring grains (wheat, barley) and grasses (crested wheatgrass).

7. For soils-agricultural purposes it is promising to carry out an aerospace survey in different seasons of the year. The early spring period is an important time for studying the moisture content of soils using remote methods. The best time for a survey for the purpose of mapping of the soil cover is when the soil surface is dried out and the fields are plowed. Two successive summer periods (one in the phase of stem extension of grains

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and formation of fruits of agricultural crops and the other in the phase of maturing of plants) are effective for determining the development of agricultural crops (depending on soil fertility, application of fertilizers, irrigation) and in the last analysis in determining their crop yield. The autumn period is the time for determining the autumn moisture reserves of soils and study of the state of development of winter crops and soil mapping.

Using a space photograph of the territory of the steppe zone (typical chernozems) for the spring survey period there was reliable determination of freshly plowed fields and lands on which cultivated crops had been sown. Against this background fields of winter wheat and grasses, meadow-chernozem soils of steppe ravines and gullies, as well as gray forest soils and sectors of eroded soils and poorly consolidated sands stand out in contrast. The different character of erosional dissection of soils was especially reliably determined from the photoimage of this photograph. On a summer space photograph it was virtually impossible to determine plowed meadow-chernozem soils of depressions in the region of occurrence of chernozem soils. Against the image background of gray forest soils the degree of erosion of the territory is determined clearly.

The time of carrying out the space survey in the course of the day exerts a significant influence on the photoimage of the soil cover and sown crops. In the steppe zone in the morning hours of a survey from space (June) it is easy to interpret fields with different sown crops. In a survey at midday the gully-ravine network stands out in great contrast.

An analysis of long-term changes of the soil-vegetation cover revealed a stable, modified (in part) and highly modified (meliorated territories) nature of the photoimage of the soil cover. The use of aerial photographs and space photographs of different survey years for one and the same territory is affording new possibilities for studying the dynamics of erosional processes, objective detection and prediction of changes in the soil cover accompanying melioration work.

Routine surveying at different times is the basis for objective inventorying of soils and agricultural crops, their state, development, determination and prediction of crop yields.

8. Keys for soil interpretation are prepared on the basis of an investigation and analysis of the photoimage of the soil cover of key sectors on aerial and space photographs. They include:

a) aerial and space photographs with the results of interpretation in the form of a sample of a soil map frequently compiled on a transparent base; the photographs and maps are at the same scale and when they are matched it is easy to determine the soil units and the characteristics of their photoimage; for each photograph data are given on the scale, time and form of the survey (black-and-white isopanchromatic or infrachromatic; color "natural" or spectrozonal; multizonal, multispectral with an indication of the surveyed spectral regions; IR, radar); in addition, there is indication of the natural region, in accordance with the soil-geographical regionalization, to which the photograph belongs; b) tables and keys for the interpretation of soils which contain the names of the soils and the properties of their upper horizons exerting an influence on the photoimage (content of humus, carbonates, iron oxides, salts, moisture; mechanical composition); coefficient of soil reflectivity; data on relief, vegetation and geology (soil-forming rocks) and soil interpretation criteria; explanatory text with a description of the natural conditions and the soil cover and an indication of the peculiarities of soil interpretation of the analyzed photograph; with the use of multizonal photographs there is an effect from the use of individual spectral zones or their combinations for soil identification.

9. In the present stage of development and use of aerospace methods for the study of soil resources an important economic effect is noted from the creation and revision of soil maps. The use of these methods makes it possible to compile soil maps which are more precise and more complete in content. At the same time, using remote techniques it has become possible simultaneously over extensive territories to study the properties of soils in the field, which earlier was not possible in research.

In the compilation of soil maps from multizonal aerospace photographs with use of an image analyzer ("Kvantimet-720") there is an increase in the role of preliminary office interpretation of soils and detection of their properties, having great importance for increasing fertility. When samples of soil interpretation and soil maps of a similar or larger scale than the future map compilation are available for the investigated region, a map of preliminary soil interpretation is compiled in the office period and is then refined.

In the case of a large-scale soil survey with the use of aerial methods there is a reduction in the number of test pits by a factor of 2-3, with some increase in the number of primary and secondary pits as a result of more complete information on the soil cover which is provided by aerial photographs.

It was established that in medium-scale mapping of soils in the dry steppe and desert zones with the use of aerial methods the completeness of the content and quality of the maps increase by a factor of 2-3.

In the small-scale mapping of soils with the use of space photographs the soil maps were compiled more completely with respect to content with an objective representation of the generalized structure of the soil cover on them. In comparison with available methods (for the dry steppe and desert zones) the effect is increased by a factor of 1.5-2. Space photographs, as a result of their extensive coverage and the optical generalization of details of soil structure, made it possible to interpret and precisely map the complex soil cover of floodplains and deltas of rivers, alluvial fans of mountain rivers, areas of dry channels in the south and inaccessible meadow lowlands in Yakutia, etc. It was established that the interpretability of the soil cover and the effectiveness of study of soils and the compilation of soil maps of the territory of dry steppe and desert zones from space photographs is several times greater than in the steppe zone. This is attributable to the greater contrast of the soil cover and the lesser agricultural exploitation of soils in the deserts and semideserts.

Taking into account international data, especially from the United States, it is assumed that in the study of the soil-agricultural resources each ruble invested in the technology of remote investigations and new directions for their use will give an economic effect five times as great.

10. In the long run, for the effective use of aerospace materials in soil science and agriculture it is important to make investigations of the following scientific-methodological problems:

-- further evaluation of the information content of aerospace materials on soils and agricultural crops in different parts of the spectrum -- from the ultraviolet to the radiorange; further development of means for remote sensing of the earth's surface, qualities of soils, condition of sown crops;

-- creation of aerospace interpretation keys for soils and agricultural crops and formulation of criteria for the reliability of office interpretation;

-- investigation of the spectral brightness of soils and agricultural crops for the entire range of the electromagnetic spectrum for different natural and technical survey conditions;

-- formulation of a classification of soil cover images based on study of their texture for the purpose of enhancing the information possibilities of the used materials;

-- study of the peculiarities of the photoimage of soils and plantings of agricultural crops on aerospace materials in dependence on survey time and season;

-- development of methods for the automated (using an electronic computer) computer identification of soils and crops from aerospace photographs.

On the basis of the data collected in study of the soil cover and the condition of agricultural crops from aerospace materials it is possible to make an approach to evaluation of the fertility of different soils, the yield of agricultural crops and the productivity of mown fields and pastures.

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